Final Report

Methodology to Quantify Impact of Poultry Litter Application on Surface Water Quality

LDEQ Contract # 513920

Submitted by

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1. Summary

Control of phosphorus transport from agricultural lands to surface waters is an important consideration when attempting to prevent or control eutrophication of a water body. The goal of this project was to develop the methodology to quantify the relationship between soil phosphorus content in litter-amended pastures and the concentration of phosphorus in surface runoff. Specifically, the objectives of the project were as follows:

1) To compare measurements of soil phosphorus (P) content in soil to measured P concentration in surface runoff from field plots in established pastures which had received poultry litter applications. Four laboratory chemical analyses and a field electromagnetic survey technique, which has been used to detect ionic constituents in soils through measurement of conductivity gradients, will be used.

2) To evaluate two hydrologic transport models based on their predictive ability and ease of use, utilizing the soil P measurements described above;

3) To formulate the best combination of soil P measurement and transport model to define the relationship between soil P content and P losses in surface runoff; and

4) To provide recommendations on soil P levels desired to achieve acceptable levels of phosphorus transport from pasture lands which receive poultry litter applications.

The results of the project indicate that soil P content increased with increasing years of poultry litter application. Bray 2 soil P values in the top 0-5 cm layer ranged from 124 mg/kg for Site 1, which had received only one poultry litter application, to 1400 mg/kg for Site 4 which had received over 20 years of poultry litter application. Within pasture sites, soil P values are highly variable. Soil P values determined with four analytical techniques, Bray 1, Bray 2, Mechlich 3 and Resin, were significantly different for the moderate to high soil P sites. Total P concentration in surface runoff collected from pasture plots after simulated rainfall events increased in general in response to greater soil P content. Mean total P concentrations for four rainfall simulations were 3.22 mg/L for Site 1, 4.10 mg/L for Site 2, 5.19 mg/L for Site 3 and 6.40 mg/L for Site 4. The mean total P content in surface runoff decreased significantly with rainfall event for all but the highest soil P site, Site 4, due to the greater reservoir of stored P in the soil at that site. The mean dissolved P content in surface runoff ranged from 70 to 100% of the total P value. The rainfall duration required to produce runoff increased and the volume of surface runoff decreased from Site 1 to Site 4, due to greater infiltration of applied rainwater into soil for Sites 3 and 4. As a result, total P loading decreased from Site 1 to Site 4 for the first three rainfall simulations.

The use of electromagnetic (EM) survey technique appears to be a useful tool to predict soil P content and potential P loading to surface waters from poultry-litter amended pastures. Deep depth EM terrain conductivity measurements show a strong correlation to

soil phosphorus content due to poultry litter applications and a strong correlation with P concentration in surface runoff. Shallow EM conductivity measurements did not correlate well with concentration of P in soil or surface runoff, due to the high sensitivity to soil moisture content which can vary substantially at shallow depths.

Results of the surface water modeling calibration and verification indicate that the Epic transport model and the Resin soil P analytical method provide the best results in terms of predictive ability. Soil P values in excess of 100 mg/kg are predicted to result in surface water phosphorus concentrations of 1 mg/L or greater.

2. Introduction

Broiler production in Louisiana is concentrated in Union Parish, in hilly areas that are not suitable for row crop production. Grain for poultry feed is imported into the parish, causing a large influx of nutrients into the area (Kovar et al., 1999).

Historically, broiler litter (manure plus bedding material) was applied to pastures that were close to the broiler units and accessible most of the year. Robinson et al. (1994) analyzed soil samples from 25 pasture sites in Union Parish which had received poultry litter applications for up to 40 years. This study revealed that after four years of litter application, levels of plant-available P in the surface 15 cm of soil increased from a background average of 17 mg/kg, which is considered deficient for most crop needs, to an average of 134 mg/kg, which is adequate for crops grown on these Coastal Plain soils. After litter application of 10 years or more, concentrations of P averaged 400 mg/kg, with values as high as 800 mg/kg. In addition, elevated levels of plant-available P were found to depths of 90 cm.

Control of P transport from agricultural lands to surface waters is needed in order to prevent or minimize eutrophication of water bodies. Surface runoff from northern Louisiana pastures drains into creeks and bayous, such as Corney Bayou, which flow into Bayou D'Arbonne Lake. Corney Bayou, one of Louisiana's Natural and Scenic Rivers, has been rated as partially supportive of primary contact recreation and not supportive of fish and wildlife propagation, with pastureland runoff listed as the primary source of contamination (LDEQ, 1993).

Due to the high P adsorptive capacity of clay and organic matter, measures to control P transport often target the management of sediment loss. However, continued applications of P in excess of plant needs can saturate the adsorptive capacity of the soil and lead to migration of dissolved P (Walthall and Nolfe, 1998). Therefore, transport of dissolved P must be considered.

In several studies, P levels in surface runoff generated with simulated rainfall have been quantified on soils amended with poultry litter (Robinson and Sharpley, 1995; Sharpley, 1997; Sharpley and Sisak; 1997). The goal of this project is to develop the methodology to quantify the relationship between soil P content due to past poultry litter applications and the concentration of P in runoff water and then to use this methodology to predict P loading to surface waters from pastures.

3. Methods

3.1 Overview: The scope of this project included selection of research sites, soil sampling and analysis, electromagnetic (EM) surveys of sites, rainfall simulation, surface water collection and analysis, and hydrologic transport model evaluation, calibration and simulation. The timeline of events for the projects was as follows:

8/97	Soil samples collected over a 0.4 ha area at four pasture sites to determine initial soil P content. Field EM surveys conducted over 0.4 ha area at each site and one deep soil core collected to correlate with EM survey data.
9/97 – 4/98	Three field plots installed at each site. Plots areas fenced.
6/98	First rainfall simulation conducted. Surface runoff water collected. Soil samples collected from area immediately adjacent to field plots.
6/99	Second rainfall simulation conducted. Surface runoff water collected.
10/99	Third rainfall simulation conducted. Surface runoff water collected.
12/99	Fourth rainfall simulation conducted. Surface runoff water collected. Soil samples collected from area immediately adjacent to field plots. EM survey conducted over 0.4 ha area at each site.

3.2 Experimental site description: Four established pasture sites, identified as Sites 1, 2, 3 and 4, in the Lake D'Arbonne watershed in Union Parish, Louisiana were selected for the study. Poultry litter (manure plus rice hull bedding) had been applied to each of the four sites for a period of time ranging from one year for Site 1 to more than 20 years for Site 4 (Figures 1, 2, 3 and 4). Site 1 had been cleared of pine trees 3-5 years prior to the study, and had sparse vegetative cover at the initiation of the project. The dominant forage cover at the sites is Bermuda grass (*Cynodon dactylon* (L.) Pers.). The soils are classified as follows: Site 1 - Malbis fine sandy loam; Site 2 - Malbis fine sandy loam; Site 3 - Sacul very fine sandy loam; Site 4 - Darley gravelly fine sandy loam (Soil Survey Staff, 1997)

3.3 Soil analytical methods:
Composite soil samples were collected in August, 1997 over a 0.4 ha area at each site to determine the initial soil P content. Samples were collected at depths of 0-5 cm, 5-15 cm and 15-30 cm. Soil samples were analyzed for available P via Bray 2 extraction (Bray and Kurtz, 1945), exchangeable calcium, potassium, magnesium, and sodium via extraction with 1.0 N ammonium acetate, pH in water, and organic matter via Walkley-Black oxidation (Donohue, 1992). Particle size was determined via the hydrometer method.

Soil samples were collected adjacent to each plot at depths of 0-5 and 5-15 cm in June 1998 and December, 1999. These samples were analyzed for available P using Bray 1 (Bray and Kurtz, 1945), Bray 2 and Mehlich 3 (Mehlich, 1984) extractions and using a chloride-saturated exchange resin technique (Kovar and Barber, 1988). The Bray 2 method uses 0.1N HCL and 0.03 M ammonium fluoride as the extractant, the Mehlich-3 method uses a mixture of 0.2 M acetic acid, 0.25 M ammonium nitrate, 0.015 M ammonium fluoride, 0.013 M nitric acid, and 0.001 M EDTA, whereas the Bray 1 method uses 0.025N HCl and 0.03 M ammonium fluoride.

Soil samples were collected adjacent to each plot at a depth of 2.5 cm for moisture analysis prior to each rainfall simulation. In addition, in August 1997, one soil sample was collected for soil anion analysis in each of the four pasture sites. Soil samples were collected at 15 cm intervals by boring one hole with a Giddings Hydraulic Soil Probe at each of the sites to a depth of ~ 3 m (10 ft). The sample depths were chosen to enable the analyses to be correlated to the results of the EM surveys. In addition, a soil core was collected from a site adjacent to Site 1, named Site 1A, because the preliminary EM survey indicated that elevated soil conductivity existed in a localized region. The elevated EM readings were unexpected, since the entire pasture had been recently cleared of trees and had received only one poultry litter application. Therefore, a total of sixty-nine soil samples were collected from the five sites. These samples were analyzed for moisture, anions (nitrate, sulfate, bicarbonate and chloride) and available P via Bray 2 extraction. Further analysis of the samples for major cations (magnesium, calcium, sodium, potassium, iron, and manganese) was initiated in order to identify and quantify the soil ions that caused the elevated EM readings for Site 1A. Moisture content determinations were conducted as described in Page (1982). Chloride determinations were performed by mixing 50 g of wet soil in 100 ml of distilled water and determining chloride concentration with a Buchler-Cotlove chloridometer. Chloride levels were expressed as milligrams of Cl^- per gram of dry soil. Conductivity determinations were performed by mixing 50 g of dry soil with 100 ml of distilled water and measuring conductivity with a Yellow Springs conductivity meter.

3.4 Surface water collection and analysis:

3.4.1 Field plot installation and maintenance: Three 2.1 m x 2.1 m plots were constructed in an area with 7-12 % slope within each of the four pasture sites (Figure 5). The mean slope for the three plots at each site was 11.2% for Site 1, 9.9 % for Site 2, 10.3 % for Site 3 and 11.3% for Site 4 (Table 3.4.1). Impervious metal borders were buried to a depth of 10-15 cm (4 – 6 in) around each plot (Figure 6). A runoff collection trough, consisting of a 10 cm (4 in) PVC pipe cut in half lengthwise, was installed at the bottom of each subplot by excavating soil and placing a layer of cement underneath the PVC (Figure 7). A tubing fitting was installed at the bottom corner of each trough to serve as a sample collection port. Barbed wire fences were installed around Sites 1, 2 and 3 and electric fencing was installed around Site 4 to prevent grazing dairy and beef cattle from damaging the plots. Field plots were maintained by periodically clipping the grass to a 6-cm height and lightly raking the plots to remove the clippings. The water collection troughs in each plot were cleaned and rinsed with the supply rainwater prior to each rainfall simulation.

3.4.2 Rainfall simulation: Rainfall simulations were conducted on 6/98, 6/99, 10/99 and 12/99. Simulated rainwater was prepared by filtering well water with an average conductivity of 220 μS through an ion exchange resin column (Barnstead/Thermolyne) to reduce the conductivity of the water to 20 μS, the approximate conductivity of rainwater in Louisiana. Rainwater samples collected in Louisiana over an 18-month period (6/96 - 12/97) had an average conductivity of 14.2 μS. The well water was transported to the pasture sites in a portable tank, filtered, and then stored in fiberglass holding tanks located at each site (Figure 8). The tanks were covered with plastic sheeting to prevent contamination of the treated water.

Rainfall simulations were conducted using an oscillating-nozzle rainfall simulator (Meyer and Harmon, 1979) with rainfall applied at a height of 3 m (Figure 9 and 10). The simulator was enclosed in a plastic tarp to minimize drift of water spray due to wind (Figure 11). The rainfall application area was approximately 2.1 x 1.8 m, resulting in a 0.3 m band of pasture grass at the bottom of the trough that did not receive rainfall. This application area was chosen to prevent rainfall from being applied directly into the collection trough. The duration of the rainfall simulation was set to achieve a total runoff volume of 3 - 25 L. Five rain gauges were placed in each plot to measure rainfall intensity (Figure 12). Rainwater collected from the rain gauges was analyzed in the field for pH and specific conductivity, and stored on ice in polyethylene bottles for total phosphorus (TP) and dissolved phosphorus (DP) analysis.

3.4.3 Surface water collection: During the application of simulated rain, the surface runoff from each plot was pumped with a peristaltic pump from the collection trough into a polyethylene carboy (Figure 13). After collection of the entire runoff, the carboy was placed onto a magnetic stir plate to mix the sample. Three 500-mL aliquots of the composite runoff were pumped into polyethylene sample bottles for TP analysis. Approximately 1.5 L of runoff water was pumped into a large whirl-pak for later filtration for DP analysis. The pH and conductivity of the runoff water were determined immediately after collection. The samples were stored on ice until delivered to the laboratory.

3.4.4 Water analytical methods: Water samples collected for dissolved P analysis were filtered (using 0.45-μm membrane filters that had been pre-soaked in distilled water (APHA, 1995)) and then frozen. The unfiltered and filtered samples were analyzed for TP and DP using the Sulfuric-Nitric acid digestion (option 4 of Method 4500-P B) of Standard Methods (APHA, 1995) for conversion of organic P forms to inorganic orthophosphate, followed by colorimetric determination of the orthophosphate with the Stannous Chloride method (Method 4500-P D) of Standard Methods. Two laboratory replicates of each sample were analyzed. Total suspended solids, pH and specific conductivity were determined following Standard Methods (1995).

3.5 Electromagnetic surveys: Field EM electromagnetic (EM) surveys were conducted over a 0.4 ha area at each site in August, 1997 and in December, 1999. The surveys were conducted to determine the average conductivity reading at two shallow depths (0-0.45 m (0-18 in) and 0-1.8 m (0-6 ft)) using EM meter model 38 and two deep depths (0-4.6 m

(0-15 ft) and 0-13.2 m (0-45 ft)) using EM meter model 34 (Geonics). The two sensing depths for each EM meter are obtained by using the EM transmitter and receiver coils in a horizontal dipole (HD) and vertical dipole (VD) orientation (Figure 14).

3.6 Analysis of hydrologic transport models. An evaluation of two existing hydrologic transport models was conducted based on the hydrology of the site, soil physical characteristics, and soil phosphorus content as determined by the chemical methods and EM surveys was conducted. Simulation runs were conducted to determine the sensitivity of the model to differences in soil phosphorus content as determined by the various methods. The specific procedure used was as follows:

1. Evaluate the model with no calibration:
   a. Apply the model to three plots; Site 1 Plot 2 (S1P2), Site 2 Plot 1 (S2P1) and Site 3 Plot 3 (S3P3),
   b. Run the model for rainfall simulations 1 and 4.
   c. Compare the predicted P loading to the measured values.
2. Develop relationship between soil P content (Cs) and runoff water P content (Cw)
   a. For each site (4 sites in simulation 1, and three sites for simulation 4), calculate the average Cs and Cw; the Cs values are determined for each of three soil analytical tests.
   b. Determine the relationship between Cs and Cw for each of three soil P test methods; use the data from simulations 1 and 4.
3. Calibrate the model and evaluate its performance.
   a. Apply the relationship developed in step 2 above in the model (replace the linear approach with the equation obtained in step 2)
   b. Run the model for the three sites and compare the model estimated and measured P loading
   c. Identify the soil P test method that provided the best results
4. Estimate probability curve (P loading distribution) for the soils in the watershed
   a. Define the three P levels to be used in the simulation
   b. Generate 100 1-year weather pattern for the region for each Soil P Level
   c. For each soil in the watershed, apply the model and estimate the annual P loading
   d. Determine the statistics (Min, max, mean, and Standard Deviation) for the estimated P loading; and the probability that the P concentration in surface runoff will exceed 1 mg/L.

4. Results and Discussion:

4.1 Soils:

The results of the initial soil analyses for samples collected 8/97 indicate that as the number of years of poultry litter application increased, available P and organic matter content in the soil increased (Table 4.1.1). The increase is most evident in the surface (0-5 cm) soil layer. Some movement of P into the subsoil (15-30 cm) layer has occurred at Sites 3 and 4, where poultry litter had been applied for longer periods of time. This is not surprising, given the sandy texture of the soils at the four sites (Table 4.1.2). Walthall and Nolfe (1998) have shown that P adsorption capacity is positively correlated with clay content in these Coastal Plain soils.

The results of the 6/98 soil sampling (Table 4.1.3), when soil samples were collected from an area adjacent to each plot at each site, reveal the same trend of increasing soil P content with increasing years of poultry litter application (Figure 15). These results also indicate the high degree of spatial variability in soil P within these pasture sites. At each site, the soil P content adjacent to individual field plots varies substantially, regardless of the chemical analysis used to measure soil P (Figures 16, 17, 18, 19). The results of the 12/99 sampling (Table 4.1.4) reveal the same trends.

With respect to the analytical technique used, these results indicate that in general the Bray 2 and Mechlich 3 soil P values are greater than Bray 1 or Resin exchangeable P values for each site (Figure 20). This result is due to the stronger extractants used in the Bray 2 and Mechlich 3 analyses. Hence higher available P values are typically obtained with the Bray 2 and Mechlich 3 extractions. The data shown in Figure 20 are mean values of soil P obtained from samples collected adjacent to each of the three field plots per site, and therefore include the spatial variability in soil P value per site. Comparing the mean soil P values obtained using the four chemical methods (Tables 4.1.5 – 4.1.8) indicates that for Site 1 the mean soil P values did not differ significantly due in part to the large spatial variation in soil P value at this site. For Site 2, the Mehlich 3 values are significantly greater than the soil P values obtained with the Bray 1, Bray 2, or Resin methods. For Site 3, the Bray 2 and Mechlich 3 soil P values are not significantly different from each other, and the Bray 2 is greater than the soil P values obtained with Bray 1 or Resin methods. For Site 4, Bray 2 and Mehlich 3 soil P values do not differ from each other, but are greater than the Bray 1 and Resin methods.

4.2 Water: The field results of the four rainfall simulations conducted over the course of 18 months are given in Table 4.2.1. Severe drought conditions were present for the entire northwestern portion of the state prior to Simulation 1, and below normal rainfall conditions were present prior to Simulation 2. The total volume of runoff obtained from individual plots and the rainfall duration required to achieve runoff varied greatly. For example, runoff was routinely achieved from Site 1 after 15 to 45 min of simulated rainfall, whereas a rainfall duration of greater than 60 min was required typically to produce runoff from Site 4. The abnormally short rainfall duration used for Simulation 1, Site 4, Plot 2 was postulated to be due to the extreme dryness of the soil, which caused the water to run off the plot before the soil could be wetted sufficiently to allow infiltration. In general, the mean rainfall duration required to produce runoff increased from Site 1 to 4, due in part to the increased organic matter content of the soils and improved vegetative cover present as a result of successive years of poultry litter application. The average percent of the rainwater that infiltrated at each site (volume of rainwater applied/volume of surface runoff collected) for four simulations increased from 75% for Site 1 to 98% for Site 4 (Figure 21).

The results of the phosphorus analyses of the surface runoff indicate a general trend of increasing TP content in surface runoff from Site 1 to Site 4, corresponding to the greater soil P concentration in the soils due to increased years of poultry litter application (Table 4.2.2). Mean total P concentrations for four rainfall simulations were 3.22 mg/L for Site

1, 4.10 mg/L for Site 2, 5.19 mg/L for Site 3 and 6.40 mg/L for Site 4. The relationship between TP concentration in surface runoff and soil P content appears to follow a hyperbolic or saturation function (Figure 22), which illustrates that the surface runoff TP value declines with soil P value and with increasing rainfall event. Further investigation of this data using mass-balanced based hydrologic transport models is needed to incorporate the effects of plot slope, vegetative cover, soil type and cumulative rainfall in order to determine which soil P measurement is best for predicting P concentration in surface runoff.

For Simulation 1, no significant differences in TP concentration in surface runoff were found for Sites 1 and 3 and Sites 2 and 4 ($\alpha = .05$). The TP concentration in surface runoff was significantly different for all other site comparisons. (Table 4.2.3). For Simulation 2, TP concentration in surface runoff was not significantly different for the low soil P sites, Sites 1 and 2, or for the high soil P sites, Sites 3 and 4; however, Sites 1 and 2 did differ from Sites 3 and 4 (Table 4.2.4). For simulation 3, TP concentration in surface runoff did not differ significantly for Sites 2 and 3; however, all other comparisons did differ significantly (Table 4.2.5). For Simulation 4, Sites 1, 2 and 3 differed significantly from each other in the concentration of TP in surface runoff (Table 4.2.6). Site 4 was not completed for this simulation.

Examination of the surface runoff data obtained for each rainfall simulation reveals that the TP content in surface runoff in general decreased with each simulation (Figure 23). Site 1, which had received only one poultry litter application prior to the first simulated rainfall, had a relatively high TP concentration in the surface runoff for the first rainfall simulation as compared to the TP concentrations in the runoff for the other sites. This result suggests that the poor vegetative cover and lower infiltration rate for that site allowed for greater transport of nutrients from the soil surface. The concentration of TP in the surface runoff for Site 1 decreased with rainfall simulation to a greater extent than did the TP concentration in runoff for Sites 3 or 4. This result is expected since the mass of P contained in the soil at Site 3 or 4 was much greater than the P mass contained in the soil at Site 1 or 2 initially. The TP concentration in surface runoff for Site 1 did not differ significantly for Simulations 2 and 3; however, all other comparisons did differ significantly (Table 4.2.7). For Site 2, the TP concentration in surface runoff did not differ for Simulations 2 and 4, but did differ for all other comparisons (Table 4.2.8). For Site 3, the TP concentration did not differ for Simulations 1 and 2, or 2 and 3; all other comparisons were significantly different (Table 4.2.9). Finally, for Site 4, the TP concentration did differ significantly for all simulations (Table 4.2.10).

A large percentage of the TP content in the surface runoff from each plot was present as dissolved P, ranging from 71 – 100% of the TP value (Table 4.2.2). These results suggest that effective control measures for P transport from established pastures must target dissolved P movement in addition to sediment-bound P.

The effect of water infiltration was investigated by plotting the total P loading (TP concentration in runoff multiplied by volume of runoff) for each site (Figure 24). A trend of decreasing total P loading from Site 1 to Site 4 is shown for Simulations 1 – 3, despite the increasing soil P content from Site 1 to Site 4, due to the decreasing runoff volume obtained from Site 1 to Site 4. These results indicate that soil P value alone cannot be used as a reliable indicator of TP loading to surface water. Infiltration rates, which are a function of many factors including vegetative cover, soil organic matter, and soil physical properties, must be considered. A calculation of the TP loading rate (TP load/rainfall duration) reveals that the TP loading rate for Site 1 was much greater than Site 4, due to the combined effects of TP concentration in the runoff, the relatively high runoff volume obtained and relatively short rainfall duration (Figure 25). In other words, Site 1 had a greater TP loading per minute of rainfall event than the other sites with greater soil P concentration, due to the lower infiltration of applied rainfall at Site 1.

4.3 EM Surveys

Results of the soil sample analysis for soil moisture constant and major soil anions (nitrate, sulfate, bicarbonate and chloride) are shown in Tables 4.3.1 – 4.3.3. Electromagnetic surveys conducted at the four sites in 8/97 (Table 4.3.4) indicate that a relationship exists between years of poultry litter application and deep soil EM (Figure 26). A second EM survey conducted in December 1999 revealed that the deep EM response obtained using EM meter 34, representing 15 to 45 ft deep conductivity measurements, was constant over the 2.5 yr period between surveys (Figure 27). However, the shallow EM 38 measurements (Figure 28) were quite different as a result of the greater soil moisture content in 1999 than 1997 (Table 4.3.1). This shallow (0-6 ft) EM sensitivity to changing moisture content renders the EM 38 non-responsive to soil phosphorus concentration. Therefore, the deep EM 34 response was used to correlate with soil nutrient status.

In general, the deep EM 34 response increased corresponding to the years of poultry litter applications at each site (Figure 29) except for Site 1. Site 1 appears to have an abnormally high EM response compared to the mean soil P content (Figure 30), apparently due to the occurrence of a naturally occurring iron sulfide deposit in Site 1 and adjacent Site 1A, which was originally detected with the EM survey conducted in 8/97. As a result, the EM 34 horizontal dipole (HD) and vertical dipole (VD) correlation to the sum of soil anions is similar to past observations for Sites 2, 3 and 4 only (Figure 31). However, the mean conductivity of the surface runoff for all sites correlates well with the EM 34 response (Figure 32). More importantly, the mean EM 34 HD response correlates with soil P content (Figure 33) for all sites.

Finally, the overall mean total P concentration for the four rainfall simulations, calculated as the sum of total phosphorus load for all rainfall simulations divided by the total volume of runoff collected during the rainfall simulation, increased from Sites 1 to 4 (Figure 34). This data correlated well with the EM 34 HD readings (Figure 35). Phosphorus concentration in individual hydrological events is highly variable because of the highly variable nature of soil surface conditions. However, the variability in site EM response due to surface water transport of TP from a particular site is relatively low, suggesting that deep EM measurement is a good global indication of soil phosphorus enrichment and phosphorus transport to surface water.

4.4 Water quality modeling

4.4.1 Model Evaluation

Two hydrologic water quality models, SIMPLE (Spatially Integrated Model for Phosphorus Loading and Erosion) and EPIC (Erosion Productivity Impact Calculator), were evaluated for use in estimating phosphorus content in surface runoff. The evaluation procedure involved (1) assessing the various processes adopted in each model, and (2) studying the performance of the two models by reviewing the work conducted by other researchers, i.e. conducting literature review. The evaluation work lead to the conclusion that EPIC is a more suitable model for this research. This conclusion was based on these findings:

1) The EPIC model is more comprehensive than SIMPLE. SIMPLE does not simulate crop growth, water or chemical flow in the soil profile, and evapotranspiration. SIMPLE also does not consider the transformation of organic matters to plant available phosphorus (decomposition of organic matter).

2) The phosphorus transport module used in SIMPLE is similar to the one used in EPIC.

3) EPIC is widely used, while very little literature is available on SIMPLE.

Data of soil P content and P content in surface runoff from three of the sites for Simulation 1 and 4 were used in this analysis (Table 4.4.1). Pasture sites representing three different levels of soil P, low, medium, and high were selected to determine the historical effects of litter application on P levels in the soil and associated runoff water. No new litter applications had been made to the sites one-year prior to this research.

The EPIC input file requires data describing the topography, soil characteristics, weather pattern, and management practices. The soil data for the soil types were obtained from the parish soil survey manual. Measured daily rainfall, temperature, and solar radiation data were obtained from the Ruston, Louisiana, weather station. Other important input parameters for the EPIC input files were determined from characteristics of each site. The curve number (CN) values (Table 4.4.2) for the soil at Sites 1, 2 and 3 were obtained based on the hydrologic group of the soil and for landuse of rangeland under fair conditions (Haan, 1994). CN values of 69, 69, and 79 were used to describe plots 1.2, 2.1, and 3.3, respectively. The field management section of the input file was setup for one year starting with the planting of Bermuda grass on January 1, grazing on February 1, and killing of the crop on December 31. The precipitation for June 4th, date when the experiment was conducted, was altered to simulate the rainfall event used on each plot.

EPIC's predictions of dissolved P (Cw) were compared to the observed data from the test plots. The EPIC model was initially run with no calibration of its calculation parameters. At the conclusion of these simulations it was evident that the model grossly underestimated what was actually taking place under field conditions .

EPIC's underestimation can be traced to the method used to predict P dissolved in runoff water as a function of soil P concentrations. The linear equation to determine dissolved P in runoff used in EPIC can be writing as follows:

$$Cw = Cs * 1 / kd \qquad (4.3.1)$$

Where, Cs is the concentration of P in the soil (mg/kg), Cw is the dissolved P concentration in the water (mg/L), and l/kd is the slope of the linear relationship between Cs and Cw. The value of kd used in EPIC is 175. However, Figure 36 clearly shows that the actual relationship between soil P concentration and P in runoff is not linear. This relationship can be better described by:

$$Cw = a\,Cs / (1 + b * Cs) \qquad (4.3.2)$$

Where, a and b are constants. This equation is a hyperbolic or saturation function.
To improve EPIC performance, an equation to calculate the kd value was developed and inserted into the model. As such, kd in EPIC was no longer a constant, but a variable. The parameter kd can be calculated by:

$$kd = Cs / Cw \qquad (4.3.3)$$

Predicted and measured P concentration in surface runoff as a function of the three soil P methods is summarized in Figure 36. The Resin soil test method has the best correlation with TP in surface runoff.

4.4.2. Model Evaluation Post Calibration:

The relationship between predicted and measured Cw values using the field data and the EPIC model are shown in Figure 37. Results of the regression indicate that the simulations based on the Resin data provided the best results.

4.4.3 Model simulations for watershed

The state soil geographic database (STASGO) published by the United States Department of Agriculture was used to identify the various soil types that are under pasture in the Lake D'Arbonne Watershed (Table 4.4.3). The data describing the soil characteristics were extracted from the soil survey database (SSURGO).

The procedure used to predict runoff of dissolved P in all the soils in the watershed was exactly the same. Thus Darley soil, which makes up the largest area in the watershed, will be used to step through the entire simulation procedure as an example for all others. The initial step was the creation of an EPIC input file.

Simulation runs were conducted using long-term weather data from Ruston, Louisiana, which was the closest weather station. The hydrologic characteristics entered into the EPIC input file were those gathered from Haan et. al 1995. Simulation runs were conducted for three P levels, 25, 100, and 250 mg/kg (Table 4.4.4). For each soil P level, simulations were conducted with 100 different, generated, 1-year weather sequences.

Also, for each soil P level, the distribution of dissolved P concentration in runoff was developed based on model results.

To analyze the results simulated by EPIC, critical limits were chosen for comparison sake. The limits that was used were a minimum critical value of 0.01 mg/L for the dissolved P critical concentration for lakes (Vollenweider,1968), and a maximum value of 1.0 mg/L flow-weighted annual average by USEPA 1986.

The predicted values were compared to the critical allowable limits noted above. For all soils and all P levels the minimum critical limit (0.01 mg/L) was exceeded 100 % of the time. For the low soil P concentration level, the maximum simulated Cw did not exceed the 1.0 mg/L critical value for all most soil types. For the high soil P level, the maximum simulated Cw exceeded the 1.0 mg/L critical value for most of the soil types.

5. Summary and Conclusions

The results of the project indicate that soil P content increased with increasing years of poultry litter application. Bray 2 soil P values ranged from 124 mg/kg for Site 1, which had received only one poultry litter application to 1400 mg/kg for Site 4 which had received over 20 years of poultry litter application. These results also indicate the high degree of spatial variability in soil P within these pasture sites. This variability results in the need for many replicate samples to be collected to accurately assess the soil P content for an entire pasture. Bray 2 and Mechlich 3 soil P values in general were greater than Bray 1 or Resin exchangeable P values, especially in the 0-5 cm soil layer at the moderate to high soil P sites (> 200 mg/kg soil P), due to the stronger extractants used.

Concentration of total-P in surface runoff and the volume of surface runoff produced after simulated rainfall varied greatly for the individual plots. In general, total P concentration in surface runoff after simulated rainfall increased in response to greater soil P content. Mean total P concentrations for four rainfall simulations were 3.22 mg/L for Site 1, 4.10 mg/L for Site 2, 5.19 mg/L for Site 3 and 6.40 mg/L for Site 4. The mean dissolved P content in surface runoff ranged from 70 to 100% of the total P value, indicating that control of dissolved P transport to surface waters must be considered in addition to particle- or sediment-bound P. In addition, the mean total P content in surface runoff decreased significantly with rainfall event for all but the highest soil P site, Site 4, due to the greater reservoir of stored P in the soil at that site. For individual rainfall events, the rainfall duration required to produce runoff increased and the volume of surface runoff produced decreased from Site 1 to Site 4, due to greater infiltration of applied rainwater at Sites 3 and 4. As a result, total P loading decreased from Site 1 to Site 4, although soil P content increased from Site 1 to Site 4. Since soil type and plot slope did not vary greatly for each site in this study, the main factors that affect water infiltration that varied were vegetative cover and soil organic matter content due to successive years of poultry litter application. Thus, these results indicate that the beneficial impact of poultry litter application on water infiltration, due to increased vegetative cover and soil organic matter content, offsets the impact of high soil P content with respect to P loading to surface waters. In addition, although poultry litter application rates were not determined in this project, the results from Site 1 suggest that application of poultry litter to sparsely vegetated land should follow a graduated application rate. A low rate of application should be used until vegetation is established, then the application rate could be increased until the recommended rate for the site is reached.

The use of electromagnetic (EM) survey technique appears to be a useful tool to predict potential P loading to surface waters from poultry-litter amended pastures. Deep depth EM terrain conductivity measurements show a strong correlation to soil phosphorus content due to poultry litter applications and a strong correlation with P concentration in surface runoff. Shallow EM conductivity measurements did not correlate well with concentration of P in soil or surface runoff, due to the high sensitivity to soil moisture content which can vary substantially at shallow depths. These results indicate that EM 34 offers the potential to serve as a rapid and reasonably accurate tool to assess the eutrophication potential of a particular watershed, and further, to assist in locating the source of phosphorus loading to the surface water of an agricultural watershed.

Results of the surface water modeling calibration and verification indicate that the Epic transport model and the Resin soil P analytical method provide the best results in terms of predictive ability. Soil P values in excess of 100 mg/kg are predicted to result in surface water phosphorus concentrations of 1 mg/L or greater.

Conclusions and/or recommendations that can be made are as follows:

- Concentration of P in surface runoff from established pastures will be primarily in the dissolved form. Thus, control measures for P transport must target dissolved P movement.
- Soil P values alone do not determine the potential TP loading from an established pasture site. Sites with high soil P content may not result in high TP loading to surface water if good quality pasture is established. Use of P index values which incorporate factors such as vegetation and slope in addition to soil P value is warranted.
- Soil P values exhibit a high degree of spatial variability. Deep EM surveys offer the potential to rapidly and accurately assess soil P conditions on a pasture or watershed scale.
- Poultry litter application to recently cleared or sparsely vegetated sites should follow a graduated application rate, with low rates used until vegetation is established.

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DEDICATION

The investigators would like to dedicate this research work to Mr. Malcolm Gaspard, former Research Technician in the Department of Biological and Agricultural Engineering at LSU. Malcolm worked tirelessly and enthusiastically on the field work and instrumentation for this project for three years before succumbing to cancer in December, 1999.

Table 3.4.1. Percent slopes of individual plots at four pasture sites.

Plot	Site 1	Site 2	Site 3	Site 4
1	10.8	10.9	10.1	11.2
2	12.3	7.9	10	10.8
3	10.4	10.8	10.9	11.8
Mean	11.2	9.9	10.3	11.3

Table 4.1.1. Chemical properties of litter-amended soils collected 8/97 from four sites in Union Parish, Louisiana.

Site	Depth, cm	Avail. P, (Bray 2) mg/kg	Exch. K, mg/kg	Exch. Ca, mg/kg	Exch. Mg, mg/kg	Exch. Na, mg/kg	pH	O.M. %
1	0-5	124	99	394	68	17	4.5	1.37
1	5-15	27	80	273	125	11	4.5	0.37
1	15-30	15	102	321	282	21	4.6	0.03
2	0-5	286	112	754	135	17	5.4	1.71
2	5-15	90	64	396	84	16	6.0	0.51
2	15-30	21	119	468	243	25	5.1	0.30
3	0-5	751	170	1631	195	19	5.8	2.74
3	5-15	291	80	820	80	17	6.1	1.03
3	15-30	212	220	1487	500	48	5.4	0.41
4	0-5	1409	167	1491	218	13	5.5	3.10
4	5-15	493	72	407	65	11	5.6	0.55
4	15-30	258	78	229	52	11	5.7	0.01

Table 4.1.2. Particle size classification of litter-amended soils collected 8/97 from four sites in Union Parish, Louisiana.

Site	Depth, cm	Clay, %	Silt, %	Sand, %	Class
1	0-5	2.5	23.6	73.9	ls
1	5-15	10.1	22.1	67.8	sl
1	15-30	20.4	23.3	56.3	scl
2	0-5	2.5	19.4	78.1	ls
2	5-15	2.5	20.5	77.0	ls
2	15-30	15.2	19.6	65.2	sl
3	0-5	7.6	20.0	72.4	sl
3	5-15	7.5	22.3	70.2	sl
3	15-30	36.3	23.9	39.8	cl
4	0-5	2.5	17.8	79.7	ls
4	5-15	5.0	14.0	81.0	ls
4	15-30	10.1	15.6	74.3	sl

Table 4.1.3. Comparison of soil P values at four sites for samples collected 6/98.

Plots	Plot	Depth	Bray 1	Bray 2	Mehlich 3	Resin
		cm	--------------	-----mg/kg	--------------	--------------
1	1	0--5	84.6	139.0	42.0	57.9
1	2	0--5	43.4	64.8	18.5	23.9
1	3	0--5	48.3	56.0	16.7	22.5
1	1	5--15	9.0	3.8	4.3	9.1
1	2	5--15	6.0	4.4	0.5	21.2
1	3	5--15	31.3	33.3	12.0	45.3
2	1	0--5	115.4	165.3	56.6	102.6
2	2	0--5	110.0	160.0	56.5	77.8
2	3	0--5	96.1	150.8	44.7	65.8
2	1	5--15	78.3	100.5	41.8	54.9
2	2	5--15	66.0	136.1	13.6	42.9
2	3	5--15	36.4	37.9	13.1	23.1
3	1	0--5	218.7	407.4	125.1	301.5
3	2	0--5	269.9	919.5	138.8	277.7
3	3	0--5	266.6	827.5	143.9	193.7
3	1	5--15	187.8	431.4	112.2	276.1
3	2	5--15	206.5	531.6	108.6	211.8
3	3	5--15	212.7	520.0	119.6	228.7
4	1	0--5	574.17	1375.5	247.9	443.2
4	2	0--5	511.64	915.6	195.6	386.2
4	3	0--5	469.85	1301.4	234.4	356.2
4	1	5--15	511.44	378.3	207.4	298.3
4	2	5--15	361.49	225.8	126.9	212.2
4	3	5--15	418.91	252.1	158.7	195.9

Table 4.1.4. Comparison of soil P values for four sites for samples collected 12/99.

Site	Plot	Depth	Bray 1	Bray 2	Mehlich 3	Resin P
		cm	mg/kg			
1	1	0-5	62.1	72.3	72.0	28.8
1	2	0-5	36.4	41.3	43.4	14.9
1	3	0-5	48.7	44.2	63.3	18.8
1	1	5-15	17.0	15.9	19.6	8.4
1	2	5-15	3.4	1.3	4.1	7.8
1	3	5-15	23.6	20.3	27.7	8.6
2	1	0-5	108.7	137.8	166.9	44.3
2	2	0-5	77.6	92.7	107.0	33.9
2	3	0-5	98.4	106.0	130.8	42.9
2	1	5-15	74.8	72.5	96.1	21.6
2	2	5-15	54.1	54.4	62.7	20.3
2	3	5-15	75.4	79.3	86.2	25.8
3	1	0-5	246.9	457.3	413.0	127.2
3	2	0-5	250.0	613.8	453.6	138.2
3	3	0-5	262.3	561.4	420.4	132.4
3	1	5-15	199.3	266.3	262.1	100.1
3	2	5-15	229.8	352.4	301.6	123.7
3	3	5-15	223.9	366.1	316.8	111.7
4	1	0-5	494.2	1006.9	761.9	192.6
4	2	0-5	452.4	1188.7	833.6	220.2
4	3	0-5	500.8	1289.1	890.5	241.0
4	1	5-15	419.5	529.5	561.5	128.5
4	2	5-15	402.6	614.7	544.7	139.3
4	3	5-15	380.9	477.5	464.1	129.4

Table 4.1.5. Soil test method comparison for 0-5 cm soil samples collected 6/98 at Site 1.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	METHOD
A	93.97	3	Mehlich3
A			
A	86.59	3	Bray2
A			
A	58.78	3	Bray1
A			
A	34.76	3	Resin

Alpha= 0.05 df= 8 MSE= 1115.365
Critical Value of Studentized Range= 4.529
Minimum Significant Difference= 87.323

Table 4.1.6. Soil test method comparison for 0-5 cm soil samples collected 6/98 at Site 2.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	METHOD
A	367.18	3	Mehlich3
B	158.68	3	Bray2
B			
B	107.19	3	Bray1
B			
B	82.05	3	Resin

Alpha= 0.05 df= 8 MSE= 5537.165
Critical Value of Studentized Range= 4.529
Minimum Significant Difference= 194.57

Table 4.1.7. Soil test method comparison for 0-5 cm soil samples collected 6/98 at Site 3..

Means with the same letter are not significantly different.

Tukey Grouping		Mean	N	METHOD
	A	718.1	3	Bray2
	A			
B	A	552.9	3	Mehlich3
B				
B		257.6	3	Resin
B				
B		251.7	3	Bray1

Alpha= 0.05 df= 8 MSE= 22525.08
Critical Value of Studentized Range= 4.529
Minimum Significant Difference= 392.42

Table 4.1.8. Soil test method comparison for 0-5 cm soil samples collected 6/98 at Site 4..

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	METHOD
A	1197.5	3	Bray2
A			
A	892.1	3	Mehlich3
B	518.6	3	Bray1
B			
B	395.2	3	Resin

Alpha= 0.05 df= 8 MSE= 18603.08
Critical Value of Studentized Range= 4.529
Minimum Significant Difference= 356.63

Table 4.2.1: Field data for four rainfall simulations conducted in field plots in Union Parish, LA.

Simulation	Site-Plot	Date	Rainfall duration min	Rainfall intensity cm/hr	Mean intensity cm/hr	Rain conductivity µS	Rain pH	Runoff volume L
1	1-1	6/98	15	6.9	7.7	20	N/A	15
	1-2	6/98	15	5.8		20	N/A	12
	1-3	6/98	15	10.5		20	N/A	33
	2-1	6/98	40	8.8	7.1	20	N/A	7
	2-2	6/98	40	5.6		20	N/A	11
	2-3	6/98	20	7		20	N/A	3
	3-1	6/98	60	8.1	8.3	10	N/A	15
	3-2	6/98	90	8.5		20	N/A	7
	3-3	6/98	60	8.4		20	N/A	20
	4-1	6/98	100	7.7	8.2	20	N/A	0
	4-2	6/98	15	7.6		20	N/A	6
	4-3	6/98	60	9.2		20	N/A	1.5
2	1-1	6/99	45	6.1	6.2	30	7.6	13.5
	1-2	6/99	30	6.9		30	7.6	25
	1-3	6/99	30	5.7		30	7.4	32
	2-1	6/99	45	6.6	7.2	20	7.2	9
	2-2	6/99	45	8.1		20	7.4	11
	2-3	6/99	30	6.9		30	7.4	11
	3-1	6/99	70	7.6	7.7	20	6.9	7.5
	3-2	6/99	45	7.4		30	7.4	7
	3-3	6/99	45	8.2		20	7.4	12
	4-1	6/99	130	6.8	6.8	30	7.4	6
	4-2	6/99	80	7.0		30	7.4	6
	4-3	6/99	95	6.7		30	7.4	5.2
3	1-1	10/99	15	7.9	6.7	20	7.4	10
	1-2	10/99	15	5.9		30	7.2	25
	1-3	10/99	15	6.3		20	7.4	20
	2-1	10/99	15	8.5	9.2	20	6.9	15
	2-2	10/99	15	9.7		40	6.9	14
	2-3	10/99	15	9.3		50	7.4	13.5
	3-1	10/99	105	7.6	7.5	20	6.8	8
	3-2	10/99	140	7.2		30	7.1	5
	3-3	10/99	60	7.5		30	7.2	9
	4-1	10/99	85	6.8	6.8	30	7.9	2
	4-2	10/99	60	6.7		20	7.8	11
	4-3	10/99	85	7.1		20	7.8	5.5
4	1-1	12/99	30	5.8	6.7	20	7.2	12.5
	1-2	12/99	15	5.9		30	7.2	18
	1-3	12/99	20	8.4		20	7.3	25
	2-1	12/99	30	8.6	8.7	20	7.1	9
	2-2	12/99	**					
	2-3	12/99	15	8.7		20	7.2	6.5
	3-1	12/99	40	7.7	8.4	20	7.2	9.5
	3-2	12/99	50	6.5		20	7.2	8
	3-3	12/99	15	11.0		10	7.3	8
	4-1	12/99	N/C					
	4-2	12/99	N/C					
	4-3	12/99	N/C					

** Equipment failure during simulation; Sample not obtained or contaminated
N/C : Not Completed.

Table 4.2.2. Phosphorus content of surface runoff from four pasture sites for four rainfall simulations.

Simulation	SITE	PLOT	Mean TP mg/L	Std. Dev mg/L	% DP	Runoff volume L	Loading TP, mg	Runoff conductivity µS
1	1	1	7.75	0.98	86	15	116.3	250
1	1	2	4.16	0.68	100	12	49.9	170
1	1	3	4.27	1.41	100	33	140.9	190
1	2	1	7.01	1.16	100	7	49.1	200
1	2	2	6.95	1.17	96	11	76.4	220
1	2	3	9.00	2.11	100	3	27.0	290
1	3	1	4.77	1.27	100	15	71.5	150
1	3	2	5.36	0.29	100	7	37.5	100
1	3	3	7.53	0.69	93	20	150.6	140
1	4	1	.	.	.	0	.	.
1	4	2	7.77	1.09	100	6	46.6	530
1	4	3	8.08	0.21	89	1.5	12.1	390
2	1	1	3.36	0.10	100	13.5	45.4	140
2	1	2	2.81	0.08	98	25	70.3	120
2	1	3	1.27	0.05	100	32	40.6	80
2	2	1	2.59	0.20	100	9	23.3	80
2	2	2	2.00	0.33	100	11	22.0	70
2	2	3	1.60	0.17	100	11	17.6	70
2	3	1	6.12	0.46	100	7.5	45.9	130
2	3	2	5.02	0.09	97	7	35.1	130
2	3	3	5.45	0.06	100	12	65.4	120
2	4	1	6.39	0.12	100	6	38.4	180
2	4	2	3.80	0.24	100	6	22.8	210
2	4	3	5.91	0.59	100	5.2	30.7	150
3	1	1	4.04	0.63	100	10	40.4	120
3	1	2	3.20	0.15	100	25	80.0	130
3	1	3	1.88	0.12	71	20	37.6	100
3	2	1	5.21	0.09	91	15	78.1	130
3	2	2	3.99	0.08	96	14	55.9	130
3	2	3	4.00	0.10	98	13.5	54.0	140
3	3	1	5.56	0.07	59	8	44.5	150
3	3	2	3.22	0.07	100	5	16.1	120
3	3	3	5.54	0.14	100	9	49.9	160
3	4	1	5.92	0.43	80	2	11.8	240
3	4	2	6.50	0.07	98	11	71.6	140
3	4	3	7.61	0.26	100	5.5	41.9	220
4	1	1	1.46	0.10	100	12.5	18.2	60
4	1	2	0.92	0.13	89	18	16.5	40
4	1	3	0.48	0.05	76	25	12.0	30
4	2	1	1.53	0.17	80	9	13.8	40
4	2	2	N/A	N/A	N/A	N/A	N/A	N/A
4	2	3	1.45	0.13	100	6.5	9.4	40
4	3	1	4.38	0.74	100	9.5	41.6	80
4	3	2	3.40	0.23	96	8	27.2	70
4	3	3	3.53	0.13	100	8	28.3	60

Table 4.2.3: Site comparison for total P concentration in surface runoff for Simulation 1.

SITE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
4 - 2	-1.5093	0.0396	1.5886	
4 - 3	0.6296	2.2594	3.8891	***
4 - 1	0.8665	2.3920	3.9176	***
2 - 4	-1.5886	-0.0396	1.5093	
2 - 3	0.9894	2.2197	3.4501	***
2 - 1	1.2639	2.3524	3.4409	***
3 - 4	-3.8891	-2.2594	-0.6296	***
3 - 2	-3.4501	-2.2197	-0.9894	***
3 - 1	-1.0681	0.1327	1.3335	
1 - 4	-3.9176	-2.3920	-0.8665	***
1 - 2	-3.4409	-2.3524	-1.2639	***
1 - 3	-1.3335	-0.1327	1.0681	

Alpha= 0.05 Confidence= 0.95 df= 95 MSE= 2.848296
Critical Value of Studentized Range= 3.698

Comparisons significant at the 0.05 level are indicated by '***'.

Table 4.2.4. Site comparison for total P concentration in surface runoff for Simulation 2.

SITE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
3 - 4	-0.7286	0.1160	0.9606	
3 - 1	2.3564	3.2133	4.0703	***
3 - 2	2.6509	3.4955	4.3402	***
4 - 3	-0.9606	-0.1160	0.7286	
4 - 1	2.2404	3.0973	3.9543	***
4 - 2	2.5349	3.3795	4.2242	***
1 - 3	-4.0703	-3.2133	-2.3564	***
1 - 4	-3.9543	-3.0973	-2.2404	***
1 - 2	-0.5748	0.2822	1.1392	
2 - 3	-4.3402	-3.4955	-2.6509	***
2 - 4	-4.2242	-3.3795	-2.5349	***
2 - 1	-1.1392	-0.2822	0.5748	

Alpha= 0.05 Confidence= 0.95 df= 67 MSE= 0.924944
Critical Value of Studentized Range= 3.726Comparisons significant at the 0.05 level are indicated by '***':

Table 4.2.5. Site comparison for total P concentration in surface runoff for Simulation 3.

SITE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
4 - 3	1.0651	1.8290	2.5929	***
4 - 2	1.4383	2.2023	2.9662	***
4 - 1	2.7991	3.5631	4.3270	***
3 - 4	-2.5929	-1.8290	-1.0651	***
3 - 2	-0.4105	0.3732	1.1570	
3 - 1	0.9503	1.7340	2.5178	***
2 - 4	-2.9662	-2.2023	-1.4383	***
2 - 3	-1.1570	-0.3732	0.4105	
2 - 1	0.5770	1.3608	2.1446	***
1 - 4	-4.3270	-3.5631	-2.7991	***
1 - 3	-2.5178	-1.7340	-0.9503	***
1 - 2	-2.1446	-1.3608	-0.5770	***

Alpha= 0.05 Confidence= 0.95 df= 70 MSE= 0.79817
Critical Value of Studentized Range= 3.722

Comparisons significant at the 0.05 level are indicated by '***'.

Table 4.2.6. Site comparison for total P concentration in surface runoff for Simulation 4 (Site 4 not completed for this simulation).

SITE Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
3 - 2	1.8610	2.2795	2.6981	***
3 - 1	2.4450	2.8194	3.1938	***
2 - 3	-2.6981	-2.2795	-1.8610	***
2 - 1	0.1212	0.5398	0.9584	***
1 - 3	-3.1938	-2.8194	-2.4450	***
1 - 2	-0.9584	-0.5398	-0.1212	***

Alpha= 0.05 Confidence= 0.95 df= 45 MSE= 0.214778
Critical Value of Studentized Range= 3.428

Comparisons significant at the 0.05 level are indicated by '***'.

Table 4.2.7. Simulation comparison for total P concentration in surface runoff for Site 1.

Alpha= 0.05 Confidence= 0.95 df= 85 MSE= 1.682799
Critical Value of Studentized Range= 3.706

Comparisons significant at the 0.05 level are indicated by '***'.

SIM Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1 - 3	1.5242	2.5102	3.4962	***
1 - 2	2.0839	3.0700	4.0560	***
1 - 4	3.6120	4.5981	5.5841	***
3 - 1	-3.4962	-2.5102	-1.5242	***
3 - 2	-0.5734	0.5597	1.6929	
3 - 4	0.9547	2.0879	3.2210	***
2 - 1	-4.0560	-3.0700	-2.0839	***
2 - 3	-1.6929	-0.5597	0.5734	
2 - 4	0.3949	1.5281	2.6613	***
4 - 1	-5.5841	-4.5981	-3.6120	***
4 - 3	-3.2210	-2.0879	-0.9547	***
4 - 2	-2.6613	-1.5281	-0.3949	***

Table 4.2.8. Simulation comparison for total P concentration in surface runoff for Site 2.

SIM Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1 - 3	2.5205	3.5018	4.4831	***
1 - 2	4.8579	5.8392	6.8204	***
1 - 4	5.2848	6.4106	7.5364	***
3 - 1	-4.4831	-3.5018	-2.5205	***
3 - 2	1.2336	2.3374	3.4412	***
3 - 4	1.6747	2.9088	4.1429	***
2 - 1	-6.8204	-5.8392	-4.8579	***
2 - 3	-3.4412	-2.3374	-1.2336	***
2 - 4	-0.6626	0.5714	1.8055	
4 - 1	-7.5364	-6.4106	-5.2848	***
4 - 3	-4.1429	-2.9088	-1.6747	***
4 - 2	-1.8055	-0.5714	0.6626	

Alpha= 0.05 Confidence= 0.95 df= 75 MSE= 1.588177
Critical Value of Studentized Range= 3.716

Comparisons significant at the 0.05 level are indicated by '***'.

Table 4.2.9. Simulation comparison for total P concentration in surface runoff for Site 3.

SIM Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1 - 2	-0.7252	0.1560	1.0372	
1 - 3	0.0277	0.9088	1.7900	***
1 - 4	1.0302	1.9113	2.7925	***
2 - 1	-1.0372	-0.1560	0.7252	
2 - 3	-0.1714	0.7528	1.6770	
2 - 4	0.8312	1.7553	2.6795	***
3 - 1	-1.7900	-0.9088	-0.0277	***
3 - 2	-1.6770	-0.7528	0.1714	
3 - 4	0.0783	1.0025	1.9267	***
4 - 1	-2.7925	-1.9113	-1.0302	***
4 - 2	-2.6795	-1.7553	-0.8312	***
4 - 3	-1.9267	-1.0025	-0.0783	***

Alpha= 0.05 Confidence= 0.95 df= 72 MSE= 1.111289
Critical Value of Studentized Range= 3.719

Comparisons significant at the 0.05 level are indicated by '***'.

Table 4.2.10. Simulation comparison for total P concentration in surface runoff for Site 4.

SIM Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1 - 3	0.4730	1.3392	2.2054	***
1 - 2	1.6906	2.5737	3.4568	***
3 - 1	-2.2054	-1.3392	-0.4730	***
3 - 2	0.4849	1.2346	1.9843	***
2 - 1	-3.4568	-2.5737	-1.6906	***
2 - 3	-1.9843	-1.2346	-0.4849	***

Alpha= 0.05 Confidence= 0.95 df= 46 MSE= 0.907813
Critical Value of Studentized Range= 3.425

Comparisons significant at the 0.05 level are indicated by '***'.

Table 4.3.1. Surface (0-5 cm) soil moisture content during field EM surveys.

Site	1997	1999
1	10%	--
2	7%	23.8%
3	18%	22.7%
4	14%	21.8%

Table 4.3.2. Soil moisture content with respect to depth at 4 borehole locations for samples collected 8/97.

Depth from Surface (ft)	Site 1	Site 1A	Site 2	Site 3	Site 4
	Moisture Content (fraction)	Moisture Content (fraction)	Moisture Content (fraction)	Moisture Content (fraction)	Moisture Content (fraction)
-0.25	.10	.13	.07	.18	.14
-0.75	.05	.15	.03	.26	.11
-1.5	.05	.20	.10	.37	.13
-2.5	.17	.23	.14	.26	.06
-3.5	.17	.27	.18	.16	.11
-4.5	.16	.25	.16	.18	.10
-5.5	.17	.26	.15	.14	.11
-6.5	.17	.27	.17	.15	.11
-7.5	.18	.25	.15	.19	.13
-8.5	.18	.26	.17	.19	.15
-9.5	.22	.25	.20	.22	.12
-10.5	.24	.26	.19	.22	.14
-11.5	.21		.22		.12
-12.5					.12
-13.5					.12
-14.5					.15
-15.5					.19

Table 4.3.3. Soil pore water conductivity, and sum of dominating anions at each borehole locations with respect to depth.

Depth from Surface (ft)	Site 1		Site 1A (Elevated ion site)		Site 2		Site 3		Site 4	
	Pore Water Conductivity (ms/m)	Sum Pore Water Anions meq/P	Pore Water Conductivity (ms/m)	Sum Pore Water Anions meq/P	Pore Water Conductivity (ms/m)	Sum Pore Water Anions meq/P	Pore Water Conductivity (ms/m)	Sum Pore Water Anions meq/P	Pore Water Conductivity (ms/m)	Sum Pore Water Anions meq/P
-0.25	4923	43	5843	11	13295	72	5342		5387	47
-0.75	4486	44	457	3	22433	202'	3840	25	7277	62
-1.5	21787	24	387	3	5272	40	2686	20	6365	53
-2.5	5260	45	560	5	7902	17	3487	22	16062	142
-3.5	6551	7	574	6	6304	44	4948	34	5122	51
-4.5	5217	42	1836	26	7575	49	4690	31	6782	61
-5.5	5504	42	4099	43	7397	45	2588	24	9825	91
-6.5	3964	31	8343	119	10172	58	1183	10	2684	37
-7.5	5028	40	10992	128	6943	43	3751	25	2107	58
-8.5	2911	27	10897	124	7323	48	921	8	4014	46
-9.5	4476	37	12335	153	3315	23	5172	38	8478	73
-10.5	679	10	11766	136	5270	34	4593	3	6703	62
-11.5	3515	28			2357	16			628	10
-12.5									2010	13
-13.5									3719	33
-14.5									855	13
-15.5									672	11

Table 4.3.4. EM 34 conductivity ranges and borehole EM values at 4 sites in 1997.

EM Survey Ranges						
Site	Sensing Depth (ft)	1	1S	2	3	4
EM Range ms/m	15	7.3-2.8	32-130	6.9-15.5	9.0-16.4	21.5-32.5
	45	8.4-29.5	15-128	7.0-16.2	8.9-28.9	30-47.5
EM @ BoreholeLocation ms/m	15	7.3	112	9.1	15.4	32.5
	45	8.8	112	15.0	28.0	47.5

Table 4.4.1. Soil phosphorus content vs total phosphorus concentration in surface runoff.

Simulation	Site	Soil P Content, mg/kg			P Concentration in Runoff, mg/L	
		Bray1	Bray 2	Resin	Mean	Std. Deviation
1	1	58.78	86.59	34.76	5.39	1.02
1	2	107.18	158.68	82.05	7.65	1.48
1	3	251.72	718.13	257.62	5.89	0.75
4	1	94.89	112.19	40.34	1.49	0.15
4	2	253.08	544.17	132.58	3.77	0.37
4	3	517.05	1197.53	395.22	7.93	0.65

Table 4.4.2. Hydrologic Characteristics used in the simulations

Hydrologic Group	Curve Number	Landuse &Condition
A	49	Range/Good
B	69	Range/Good
C	79	Range/Good
D	84	Range/Good

Table 4.4.3. D' Arbonne Watershed Soils & Hydrologic Values

Soil Name	Total Area (ac)	Hydrologic Soil Group	Curve Number
alaga	22.2	A	49
alligator	3.7	D	84
amy	24.7	D	84
angie	1003.7	D	84
bellwood	30.9	D	84
bernaldo	166.8	B	69
betis	648.5	A	49
bibb	28.4	D	84
bienville	1.2	A	49
blevins	244.5	B	69
bowie	3832.2	B	69
boykin	159.4	B	69
briley	2169.0	B	69
brimston	166.0	B	69
cahaba	834.0	B	69
commerce	3.0	C	79
crevasse	3.0	A	49
darbonne	299.0	B	69
darden	177.0	A	49
darley	24279.0	C	79
dela	1890.0	B	69
eastwood	5014.0	D	84
flo	449.0	A	49
frizzell	54.0	C	79
groom	0.6	C	79
gurdon	83.3	C	79
guyton	10798.0	D	84
haggerty	0.6	B	69
hannahatchee	55.6	B	69
harleston	270.0	C	79
hebert	2.0	C	79
iuka	3724.0	C	79
keithville	760.0	C	79
kirvin	1395.0	C	79
kolin	285.0	C	79
larue	200.0	A	49
leaf	2.0	D	84
libuse	11.0	C	79
litro	19.0	D	84
mahan	7419.0	C	79
malbis	2374.0	B	69
mclaurin	5580.0	B	69
metcalf	473.0	D	84
mollicy	0.6	C	79
natchitoches	177.3	D	84
newellton	40.0	D	84

Table (cont.)

Soil Name	Total Area	Hydroloic Soil Group	Curve Number
norfolk	20.0	B	69
ochlockonee	1132.0	B	69
ora	214.0	C	79
osier	2.0	B	69
ouachita	3.5	C	79
ozan	1.2	D	84
perry	19.0	D	84
pikeville	5.5	B	69
portland	6.7	D	84
ruston	6505.0	B	69
sacul	20506.0	C	79
sardis	3.0	C	79
savannah	1350.0	C	79
sawyer	129.0	C	79
sharkey	178.0	D	84
smithdale	2636.0	B	69
smithton	76.0	D	84
stough	4.3	C	79
tippah	5.5	C	79
toine	1.2	B	69
trep	387.0	B	69
tunica	80.0	D	84
una	111.0	D	84
warnock	259.0	B	69
wolfpen	286.0	A	49
yorktown	2.0	D	84

Table 4.4.4. Predicted P concentration in surface water for soil types in the watershed..

Soil	P Level 1					P Level 2					P Level 3				
	Min	Max	Mean	Stdev	Prob > 1ppm	Min	Max	Mean	Stdev	Prob > 1ppm	Min	Max	Mean	Stdev	Prob > 1ppm
Alaga	0.09	0.82	0.30	0.13	0	0.54	2.76	1.43	0.46	82	0.87	4.00	2.78	0.59	95
Aligator	0.21	0.92	0.52	0.17	0	0.86	2.91	1.86	0.49	97	1.69	4.21	3.14	0.55	100
Amy	0.07	0.59	0.23	0.10	0	0.51	2.36	1.25	0.39	84	1.32	3.64	2.53	0.55	100
Angie	0.13	0.72	0.33	0.12	0	0.65	2.47	1.45	0.41	87	0.93	3.77	2.77	0.53	95
Bellwood	0.14	0.79	0.39	0.15	0	0.93	2.68	1.75	0.43	95	0.92	3.97	2.96	0.49	93
Bernaldo	0.06	0.76	0.26	0.13	0	0.49	2.86	1.37	0.47	77	1.29	4.08	2.70	0.63	100
Betis	0.08	0.85	0.30	0.13	0	0.54	2.82	1.44	0.47	83	0.94	4.06	2.80	0.60	98
Bibb	0.09	0.77	0.30	0.12	0	0.51	2.64	1.36	0.45	79	1.34	3.90	2.69	0.59	100
Bienvill	0.08	0.81	0.28	0.13	0	0.56	2.85	1.48	0.48	83	0.87	4.09	2.84	0.60	99
Blevins	0.07	0.62	0.24	0.11	0	0.47	2.48	1.23	0.41	69	0.89	3.74	2.51	0.59	98
Bowie	0.08	0.78	0.29	0.12	0	0.55	2.68	1.40	0.44	82	0.69	3.94	2.74	0.58	92
Boykin	0.09	0.82	0.29	0.13	0	0.59	2.81	1.48	0.46	85	0.69	4.05	2.83	0.58	96
Briley	0.06	0.70	0.26	0.12	0	0.55	2.77	1.44	0.46	83	1.42	4.01	2.78	0.59	100
Brimston	0.11	1.09	0.34	0.16	0	0.58	3.45	1.50	0.52	83	0.75	4.64	2.83	0.67	96
Cahaba	0.08	0.77	0.29	0.12	0	0.36	3.04	1.16	0.47	57	0.72	6.04	2.30	0.94	97
Commerce	0.10	0.97	0.31	0.15	0	0.37	3.72	1.21	0.57	63	0.76	7.46	2.44	1.14	95
Crevasse	0.08	0.99	0.32	0.17	0	0.33	3.95	1.33	0.63	65	0.65	7.85	2.63	1.26	96
Darbonne	0.09	0.81	0.29	0.12	0	0.31	3.04	1.09	0.47	50	0.60	6.02	2.15	0.93	93
darden	0.08	1.11	0.33	0.16	1	0.34	4.32	1.32	0.63	66	0.66	8.58	2.62	1.25	98
darley	0.09	0.79	0.29	0.12	0	0.33	2.98	1.08	0.46	51	0.64	5.90	2.14	0.91	92
dela	0.08	1.12	0.32	0.16	1	0.34	4.34	1.28	0.61	63	0.67	8.63	2.56	1.22	97
eastwood	0.11	0.67	0.32	0.12	0	0.46	2.65	1.25	0.45	66	0.90	5.30	2.48	0.89	99
flo	0.10	0.85	0.31	0.13	0	0.35	3.23	1.15	0.49	55	0.69	6.42	2.29	0.97	96
frizzell	0.05	0.53	0.21	0.09	0	0.37	2.55	1.05	0.40	48	0.72	5.09	2.10	0.81	96
groom	0.08	0.53	0.24	0.10	0	0.38	2.39	1.04	0.39	48	0.75	4.77	2.08	0.78	96
gurdon	0.06	0.55	0.23	0.10	0	0.33	2.55	1.00	0.40	41	0.64	5.07	1.99	0.81	92
Guyton	0.09	0.68	0.28	0.11	0	0.48	2.35	1.20	0.39	74	0.79	3.57	2.47	0.56	97
haggerty	0.08	0.78	0.28	0.12	0	0.32	2.99	1.09	0.47	50	0.62	5.94	2.18	0.93	93
hannahatchee	0.07	1.16	0.32	0.16	1	0.36	4.43	1.30	0.61	65	0.71	8.80	2.60	1.22	97
hebert	0.08	0.65	0.26	0.11	0	0.34	2.63	0.99	0.43	40	0.66	5.30	2.00	0.86	91
iuka	0.10	0.88	0.33	0.13	0	0.38	3.35	1.24	0.51	63	0.74	6.66	2.45	1.02	98
keithville	0.08	0.60	0.27	0.10	0	0.40	2.41	1.06	0.40	50	0.78	4.82	2.13	0.80	98
kirvin	0.11	0.78	0.32	0.12	0	0.38	2.90	1.17	0.47	58	0.76	5.76	2.34	0.94	98
kolin	0.09	0.63	0.27	0.11	0	0.39	2.55	1.08	0.43	49	0.76	5.13	2.15	0.87	94
larue	0.10	1.25	0.36	0.17	1	0.40	4.81	1.42	0.67	72	0.80	9.56	2.83	1.33	98
leaf	0.11	0.66	0.31	0.11	0	0.42	2.53	1.15	0.42	57	0.82	5.09	2.29	0.85	99
libuse	0.10	0.68	0.28	0.11	0	0.38	2.70	1.10	0.44	54	0.76	5.37	2.19	0.88	97
litro	0.08	0.60	0.26	0.10	0	0.45	2.56	1.14	0.41	56	0.88	5.17	2.28	0.83	98
mahan	0.07	0.66	0.27	0.12	0	0.37	2.89	1.15	0.47	57	0.71	5.72	2.28	0.94	97
malbis	0.08	0.71	0.27	0.12	0	0.35	2.89	1.11	0.45	54	0.71	5.76	2.22	0.90	97
mclaurin	0.12	0.85	0.33	0.13	0	0.41	3.22	1.21	0.48	63	0.81	6.38	2.41	0.95	98
metcalf	0.08	0.66	0.26	0.11	0	0.36	2.70	1.05	0.42	47	0.71	5.42	2.11	0.84	94
mollicy	0.07	0.58	0.25	0.10	0	0.38	2.54	1.06	0.41	52	0.74	5.08	2.13	0.82	97
natchitoches	0.17	0.94	0.50	0.20	0	0.87	3.65	2.04	0.72	98	1.70	7.24	4.03	1.44	100
newellton	0.08	1.04	0.39	0.19	1	0.48	4.16	1.65	0.72	80	0.95	8.31	3.31	1.44	99

(continued)															
Soil	P Level 1					P Level 2					P Level 3				
	Min	Max	Mean	Stdev	Prob > 1ppm	Min	Max	Mean	Stdev	Prob > 1ppm	Min	Max	Mean	Stdev	Prob > 1ppm
norfolk	0.10	0.79	0.30	0.12	0	0.37	2.96	1.12	0.45	56	0.73	5.88	2.24	0.90	97
ochlockonee	0.08	0.70	0.27	0.11	0	0.38	2.86	1.12	0.43	57	0.75	5.68	2.22	0.87	97
ora	0.09	0.74	0.29	0.12	0	0.36	2.78	1.09	0.44	53	0.72	5.51	2.18	0.87	96
osier	0.09	0.83	0.30	0.13	0	0.30	3.05	1.11	0.48	51	0.58	6.02	2.18	0.96	93
ouachita	0.07	0.56	0.24	0.10	0	0.36	2.51	1.04	0.41	47	0.70	5.01	2.08	0.82	92
ozan	0.08	0.71	0.28	0.12	0	0.36	2.99	1.14	0.48	56	0.69	5.97	2.27	0.95	96
perry	0.18	1.15	0.53	0.22	4	0.72	4.28	2.04	0.83	96	1.39	8.46	4.03	1.65	100
pikeville	0.08	0.76	0.29	0.12	0	0.33	2.87	1.08	0.45	51	0.65	5.69	2.15	0.89	95
portland	0.16	0.82	0.42	0.17	0	0.65	3.14	1.64	0.64	86	1.25	6.22	3.24	1.27	100
ruston	0.06	0.71	0.26	0.12	0	0.31	2.89	1.06	0.45	49	0.62	5.73	2.11	0.89	92
sacul	0.10	0.57	0.30	0.11	0	0.48	2.59	1.27	0.44	67	0.94	5.13	2.51	0.87	99
sardis	0.08	0.58	0.26	0.10	0	0.39	2.43	1.05	0.40	50	0.76	4.86	2.10	0.81	95
savannah	0.09	0.70	0.28	0.11	0	0.33	2.58	1.02	0.41	46	0.65	5.12	2.03	0.83	92
sawyer	0.08	0.53	0.24	0.09	0	0.38	2.28	1.01	0.38	42	0.73	4.57	2.02	0.76	94
sharkey	0.21	1.21	0.56	0.22	2	0.87	4.53	2.14	0.79	98	1.69	8.95	4.22	1.57	100
smithdale	0.11	0.84	0.32	0.13	0	0.41	3.15	1.22	0.48	64	0.81	6.24	2.41	0.95	98
smithton	0.03	0.63	0.18	0.11	0	0.31	2.86	1.05	0.45	52	0.60	5.71	2.08	0.91	91
stough	0.05	0.57	0.22	0.10	0	0.31	2.63	0.98	0.41	40	0.59	5.21	1.95	0.82	91
tippah	0.10	0.58	0.27	0.10	0	0.44	2.44	1.11	0.41	53	0.86	4.91	2.22	0.81	98
toine	0.06	0.70	0.25	0.12	0	0.30	2.96	1.05	0.46	49	0.59	5.87	2.09	0.92	92
trep	0.06	0.88	0.28	0.14	0	0.34	3.74	1.25	0.56	63	0.68	7.41	2.47	1.11	97
tunica	0.11	1.07	0.39	0.18	1	0.51	4.16	1.55	0.68	78	1.01	8.29	3.10	1.36	100
una	0.11	0.64	0.28	0.11	0	0.44	2.64	1.12	0.41	55	0.86	5.31	2.23	0.82	98
warnock	0.08	0.77	0.28	0.12	0	0.35	2.92	1.09	0.44	52	0.68	5.79	2.17	0.88	96
wolfpen	0.07	0.76	0.27	0.13	0	0.35	3.22	1.16	0.49	56	0.69	6.38	2.30	0.97	96
yorktown	0.19	1.09	0.51	0.20	2	0.73	4.06	1.95	0.74	96	1.42	8.02	3.84	1.47	100

FIGURES

Figure 1: Site 1.

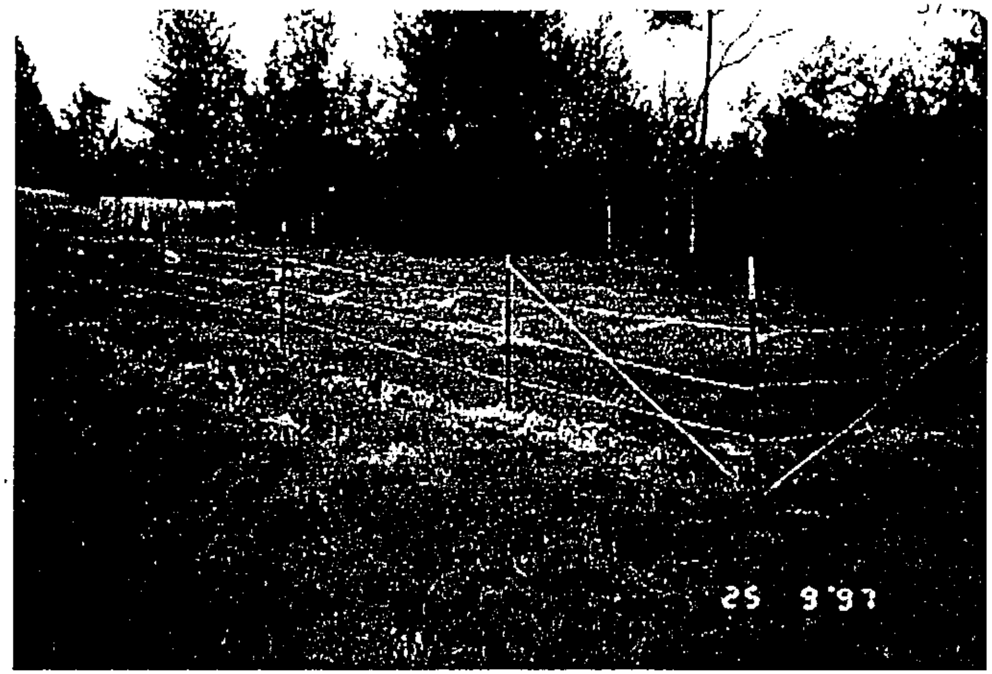


Figure 2: Site 2.

Figure 3: Site 3.

Figure 4: Site 4.

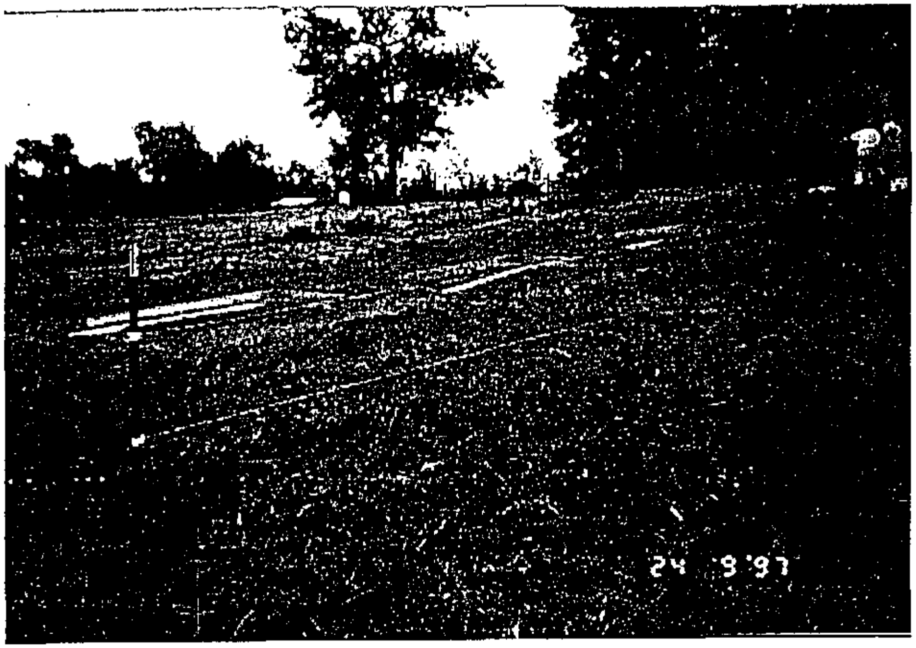


Figure 5: Plot layout at Site 4.

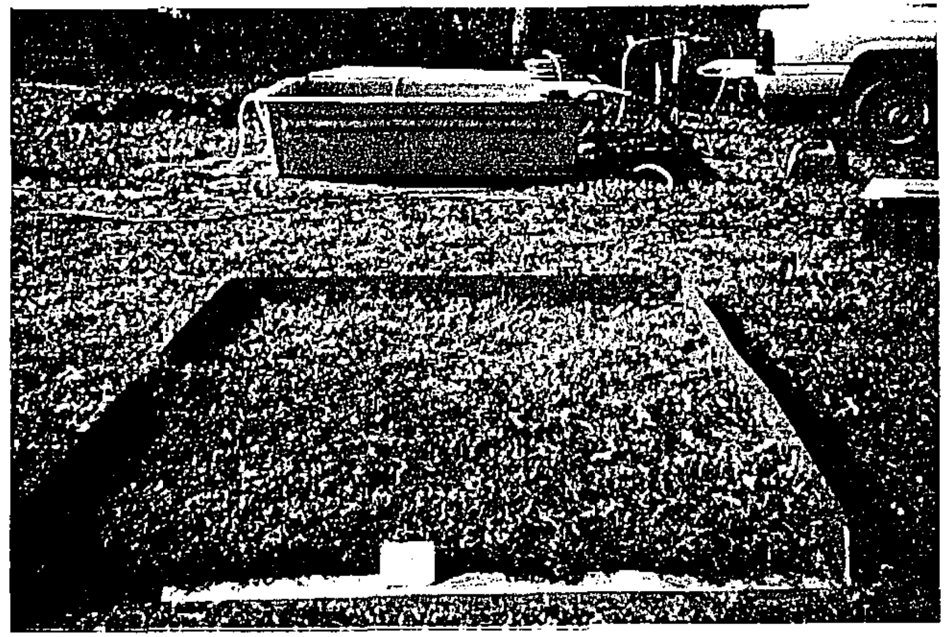


Figure 6 : Field plot with metal border.

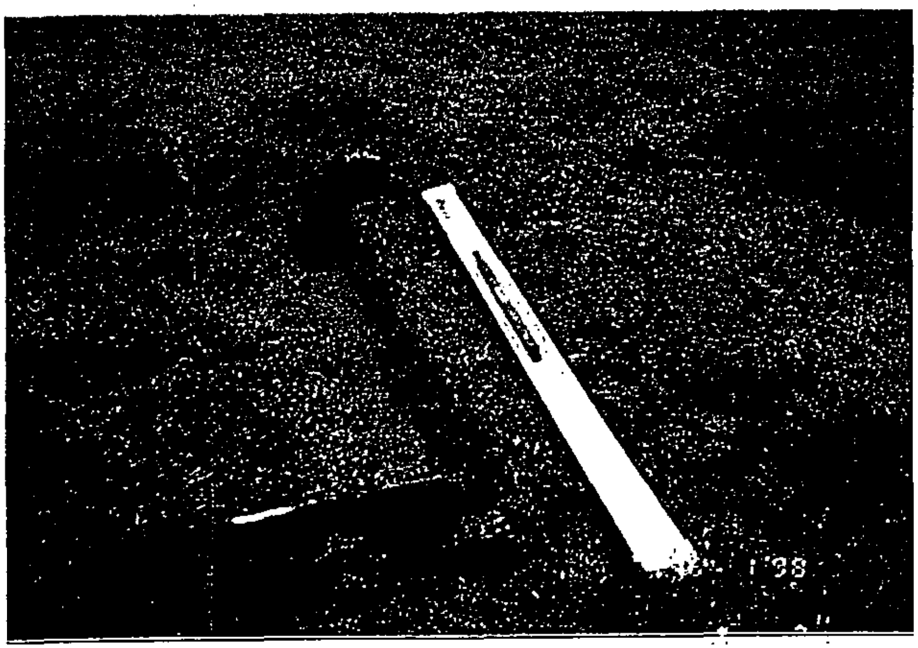


Figure 7: Installation of runoff collection trough.

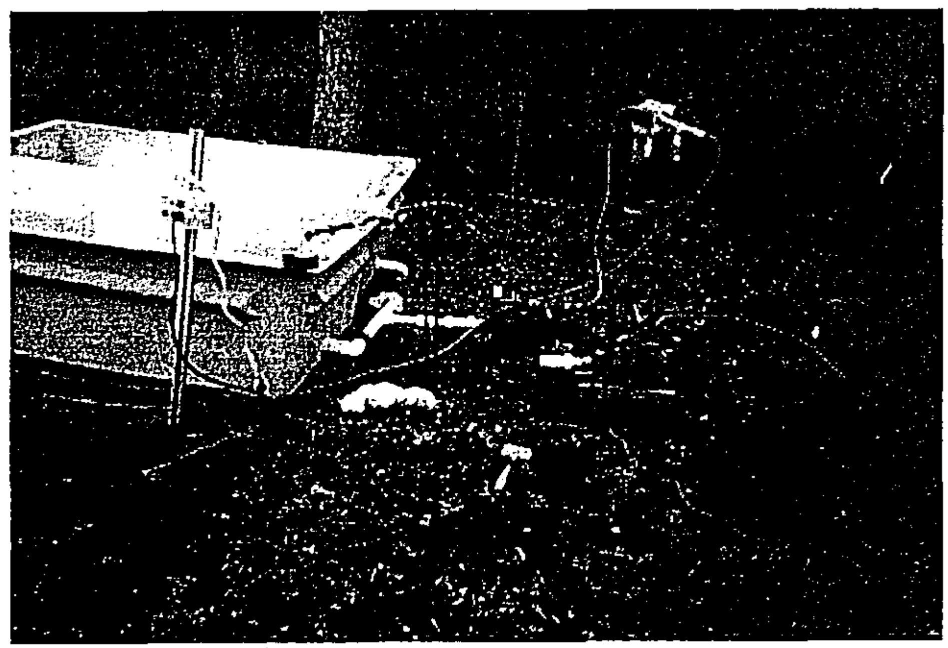


Figure 8: Water filtration apparatus.

Figure 9: Rainfall Simulator.

Figure 10: View of oscillating nozzle on rainfall simulator.

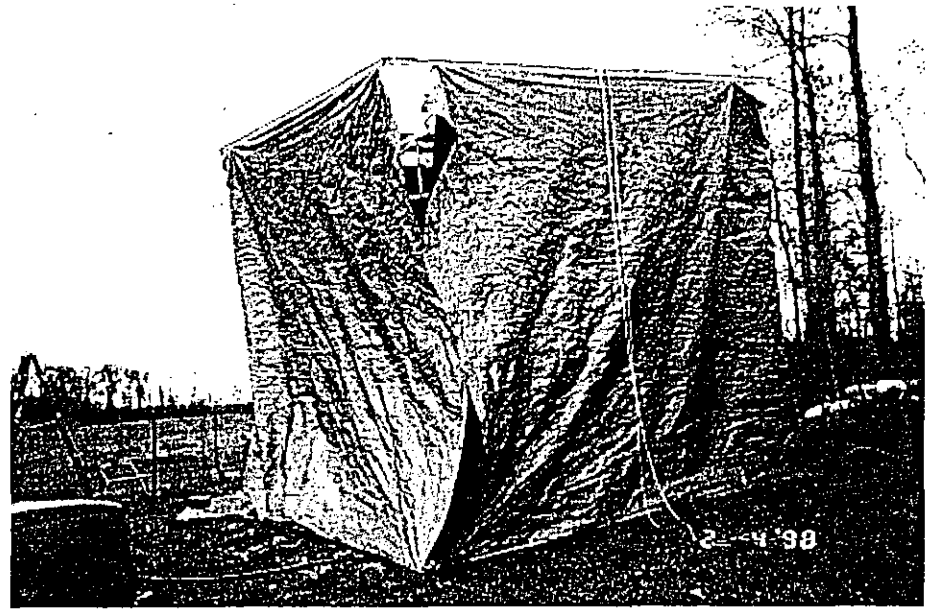


Figure 11: Wind screen around rainfall simulator.

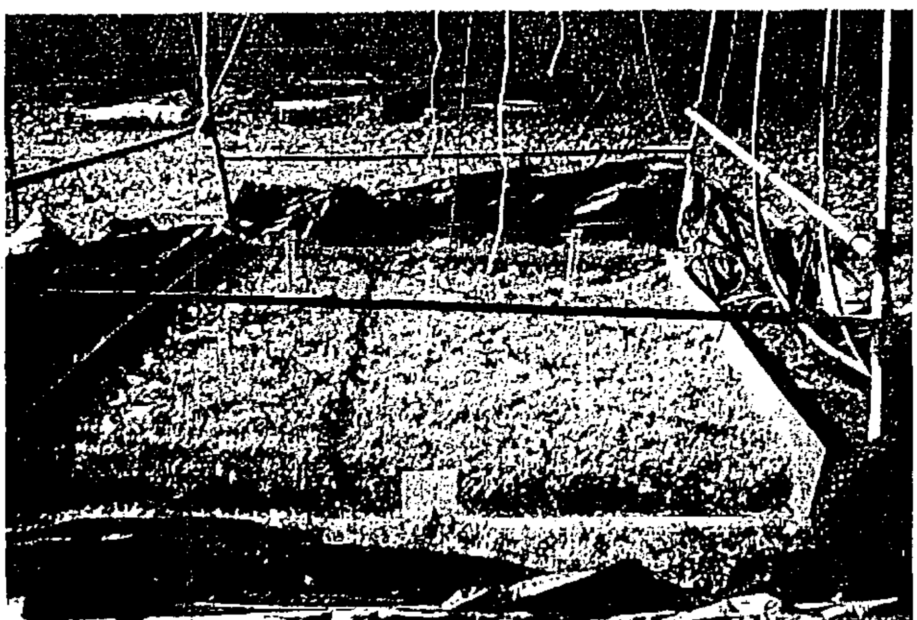


Figure 12: Rain gage layout on plot.

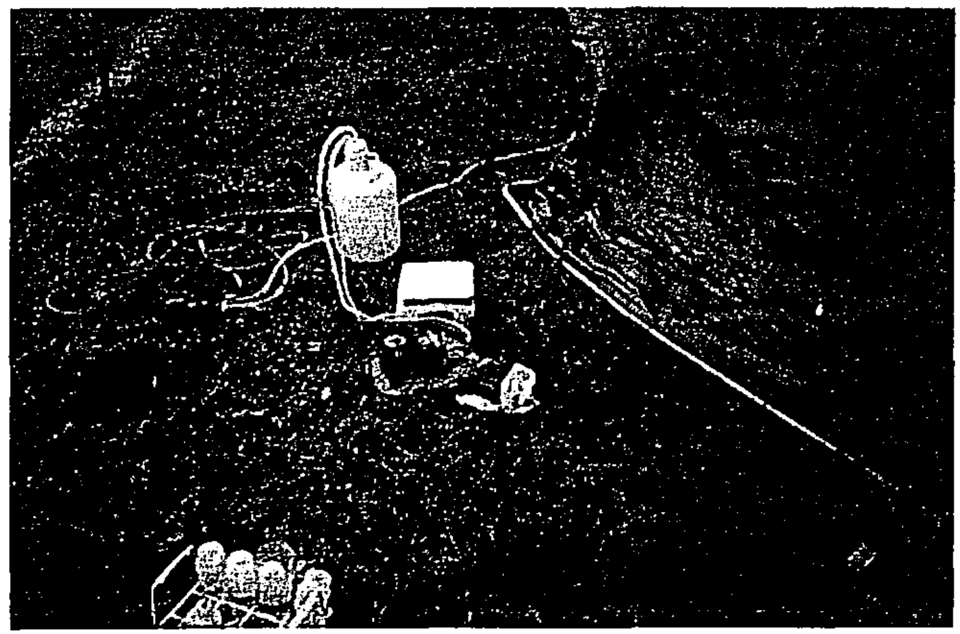


Figure 13: Runoff collection apparatus.

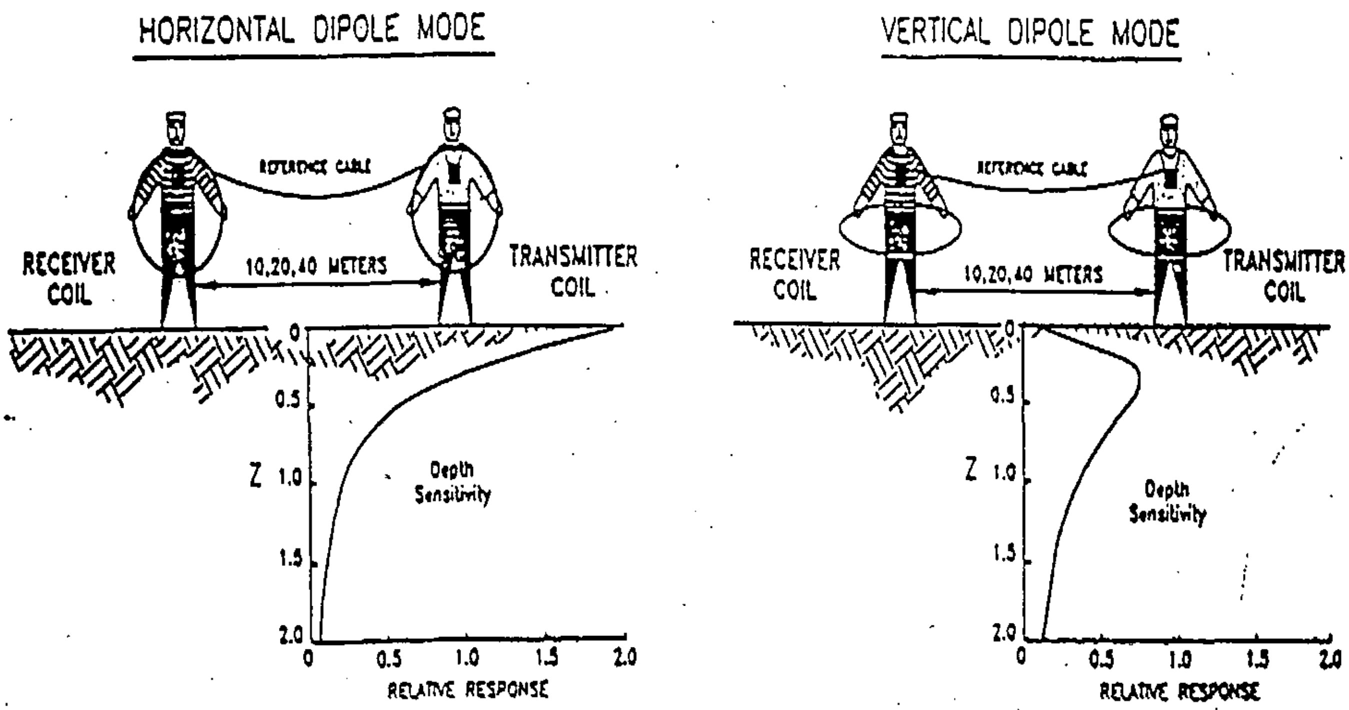


Figure 14: EM 34 meter response vs depth (Z=depth/intercoil spacing) for horizontal and vertical dipole positions.

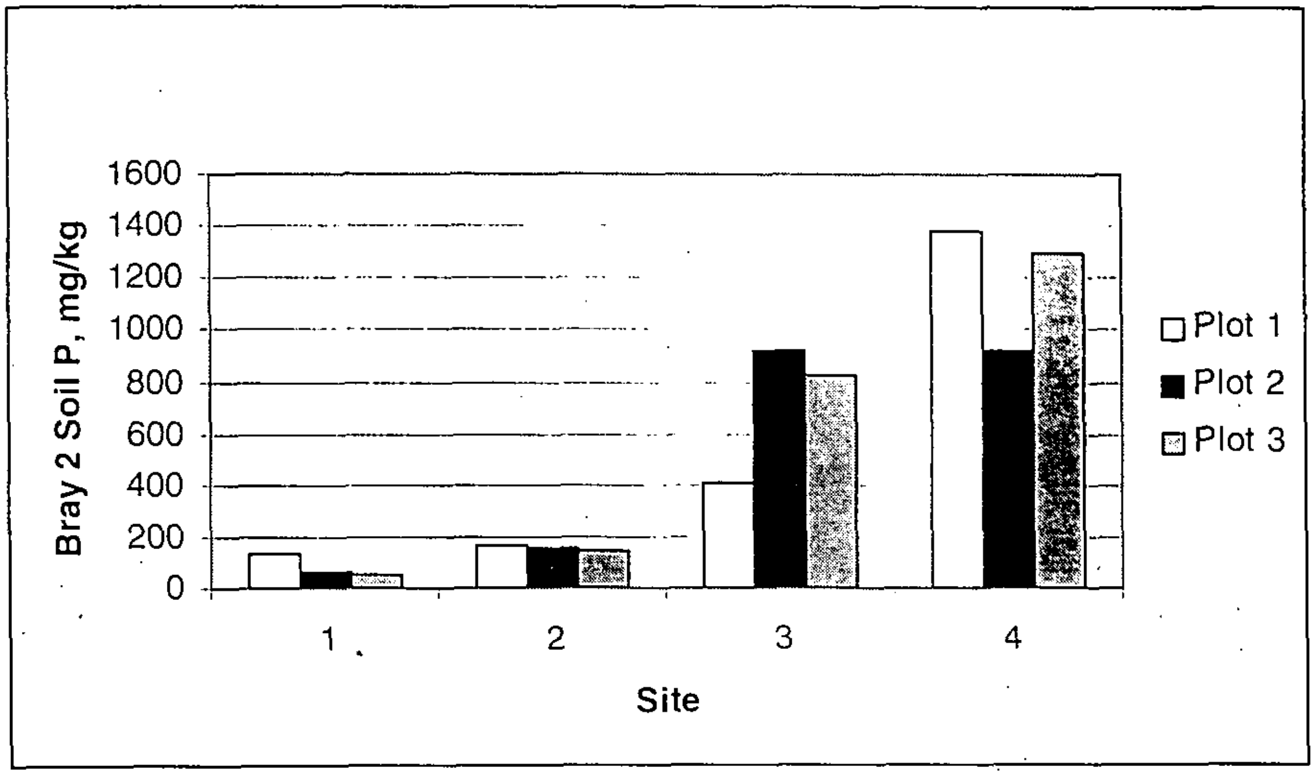


Figure 15: Bray 2 soil P values for samples collected adjacent to plots at 0-5 cm depth in 6/98.

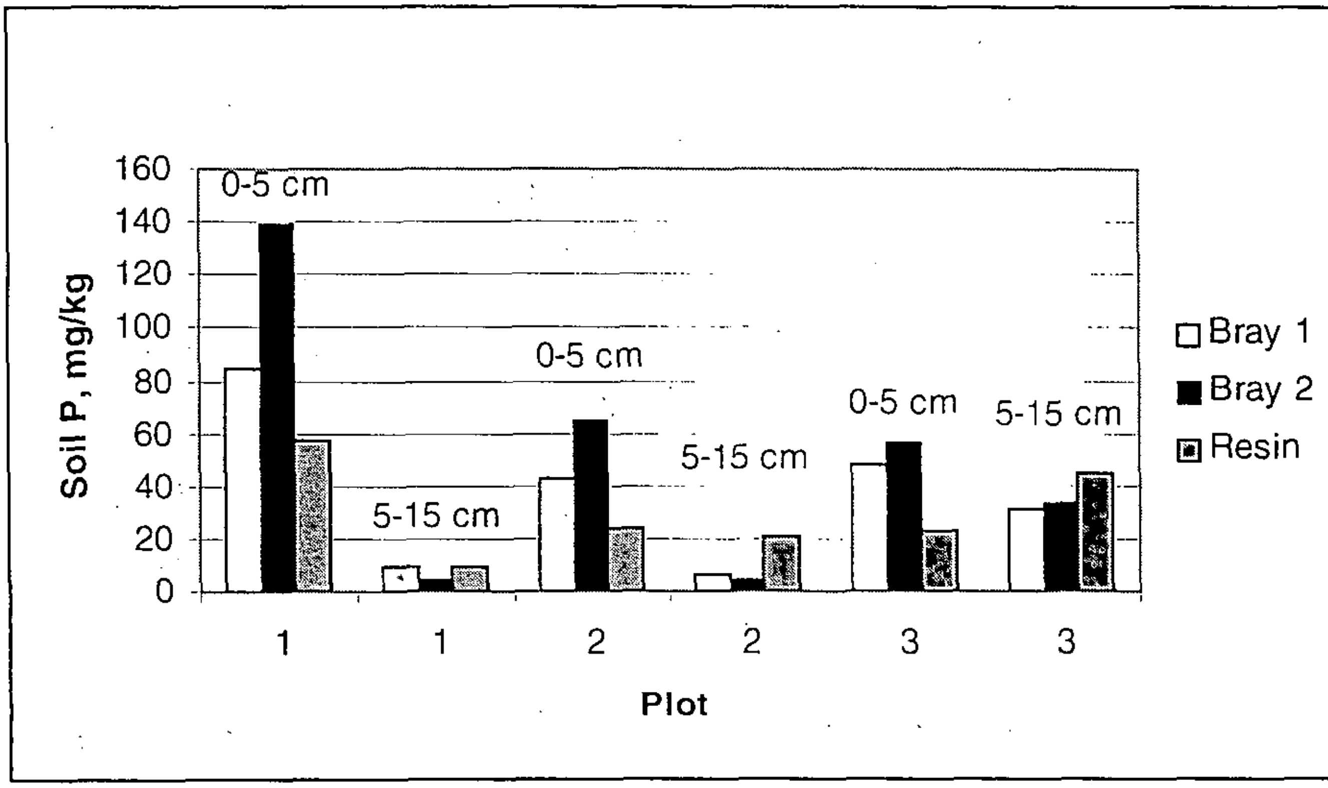


Figure 16: Variation in soil P content for three plots at Site 1 measured with Bray 1, Bray 2 and Resin analytical techniques.

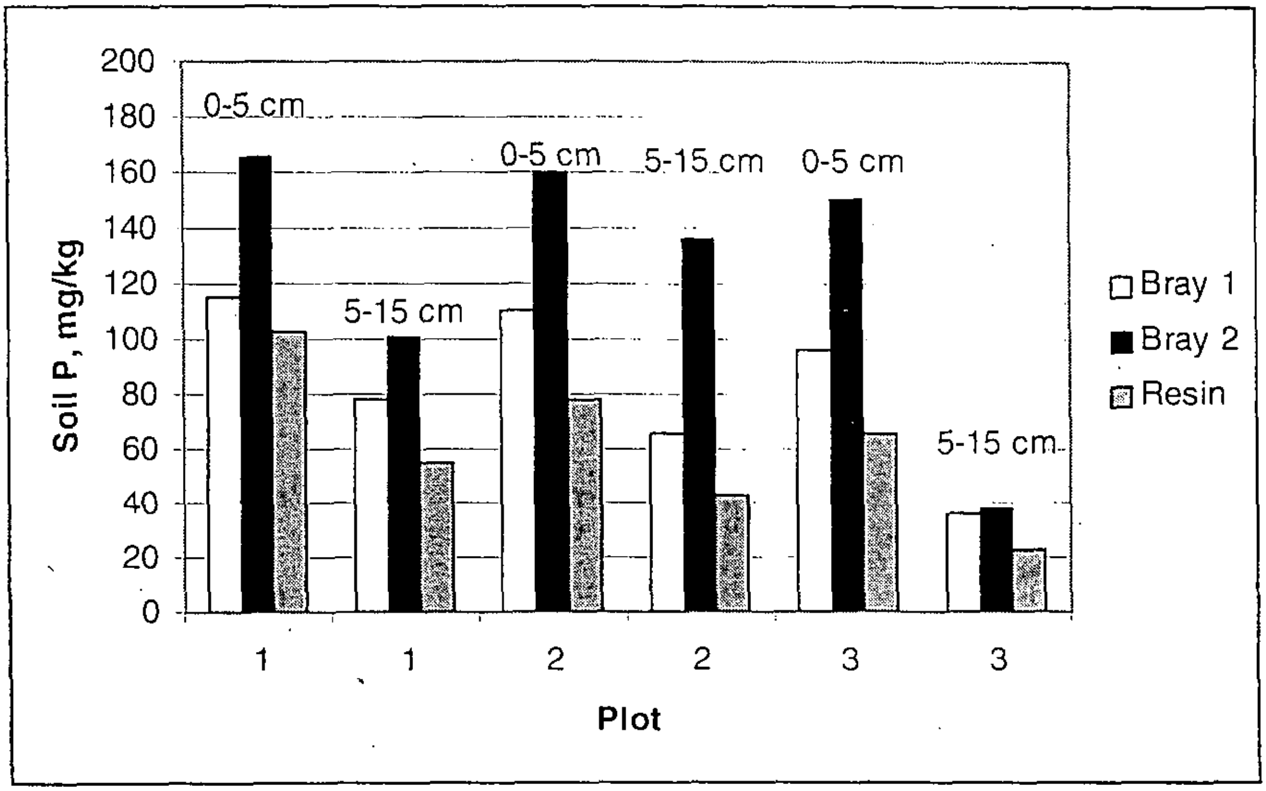


Figure 17: Variation in soil P content for three plots at Site 2 measured with Bray 1, Bray 2 and Resin analytical techniques.

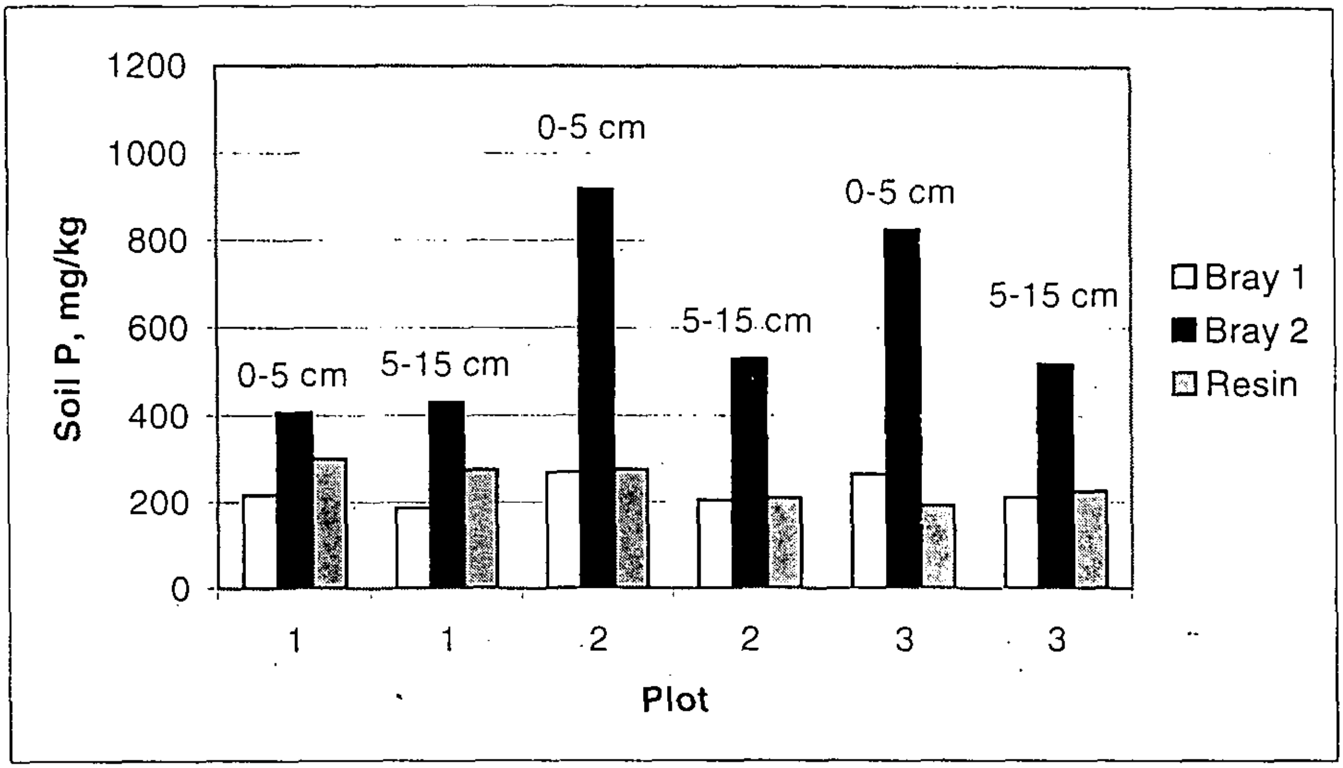


Figure 18: Variation in soil P content for three plots at Site 3 measured with Bray 1, Bray 2 and Resin analytical techniques.

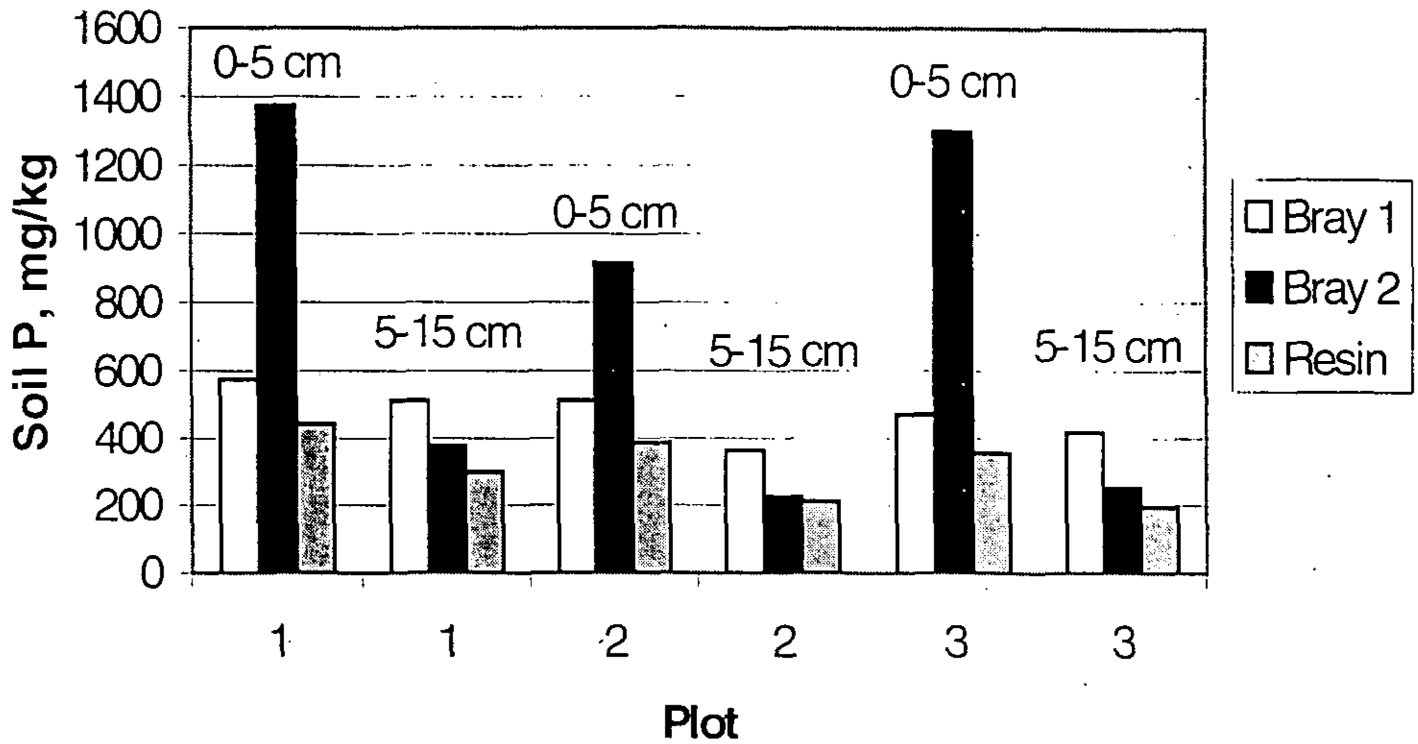


Figure 19: Variation in soil P content for three plots at Site 4 measured with Bray 1, Bray 2 and Resin analytical techniques.

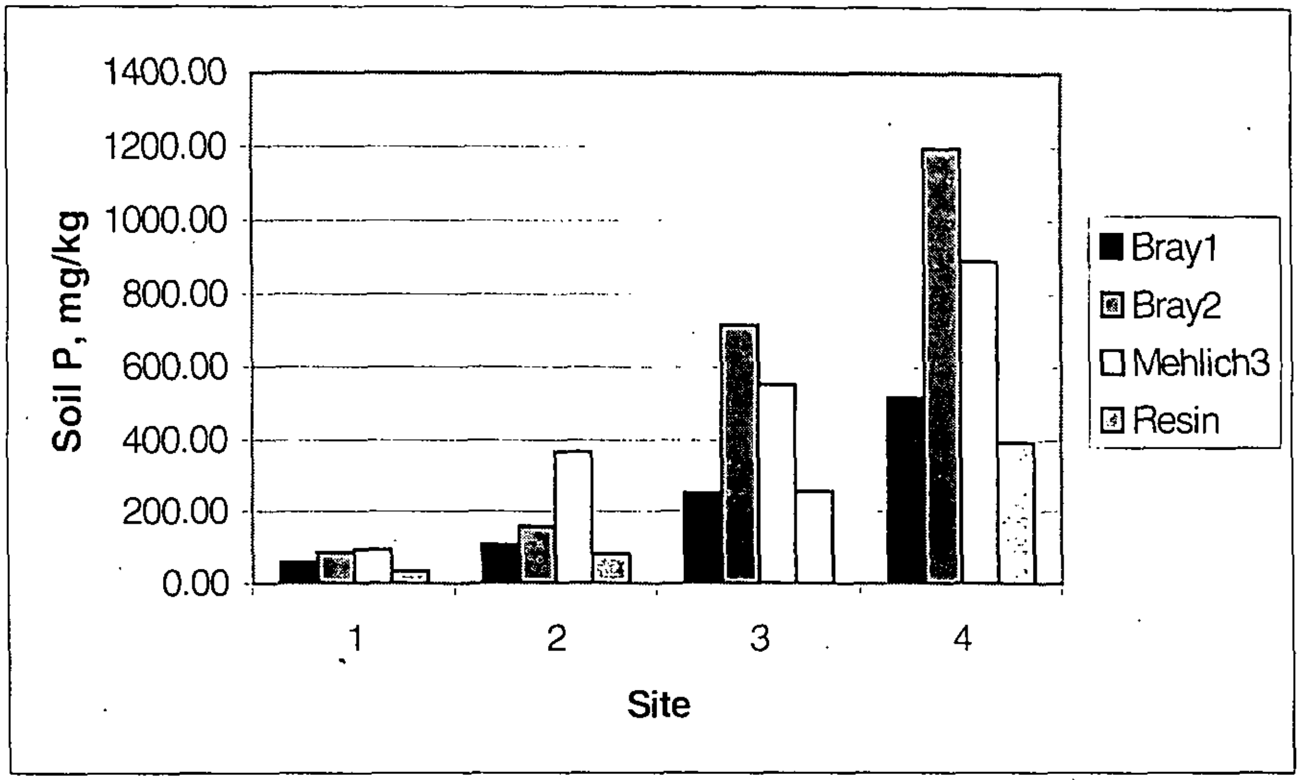


Figure 20: Comparison of mean soil P values using four analytical methods for 0-5 cm samples collected 6/98.

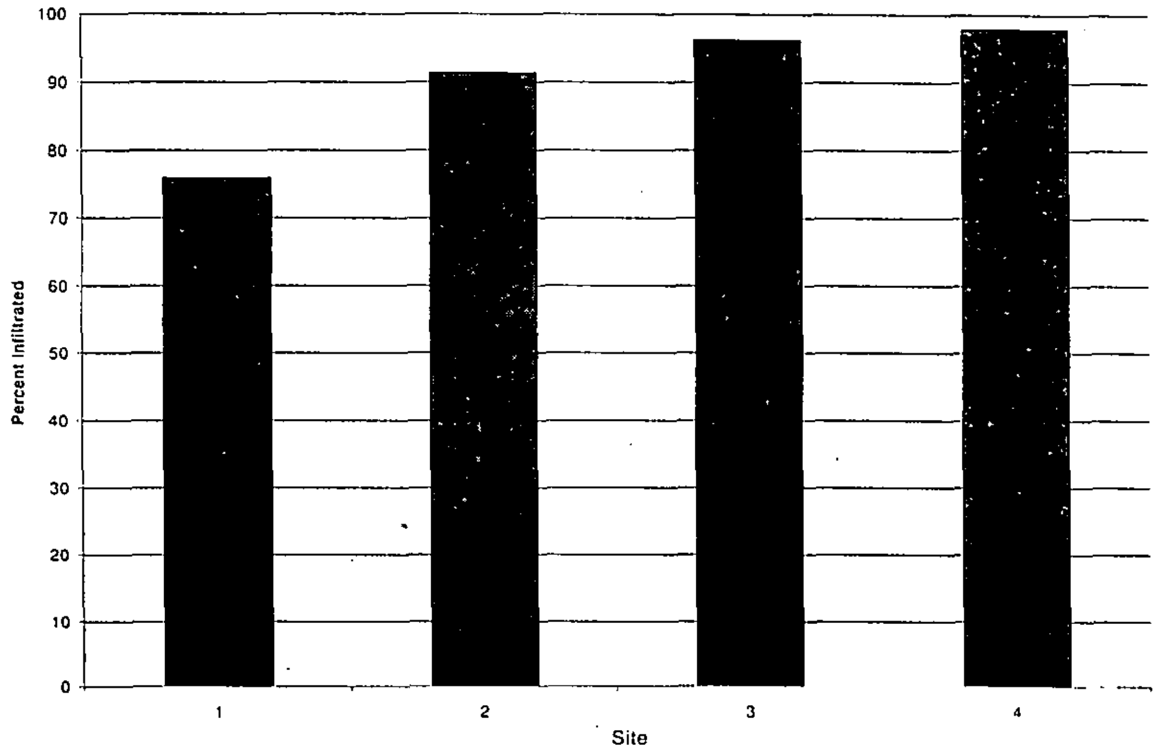


Figure 21: Mean percent infiltration for each site.

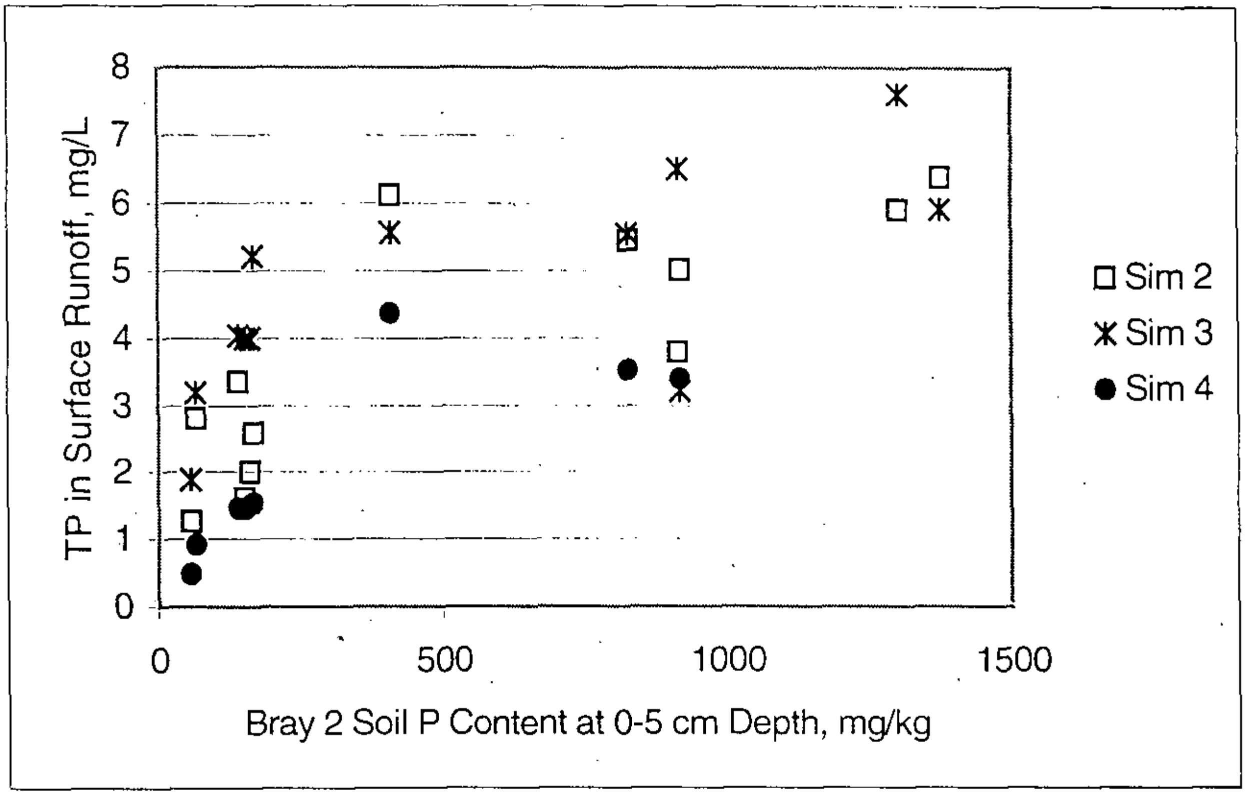


Figure 22: Total P concentration in surface runoff from individual plots as a function of soil P concentration measured at 0-5 cm depth for rainfall simulations 2, 3 and 4.

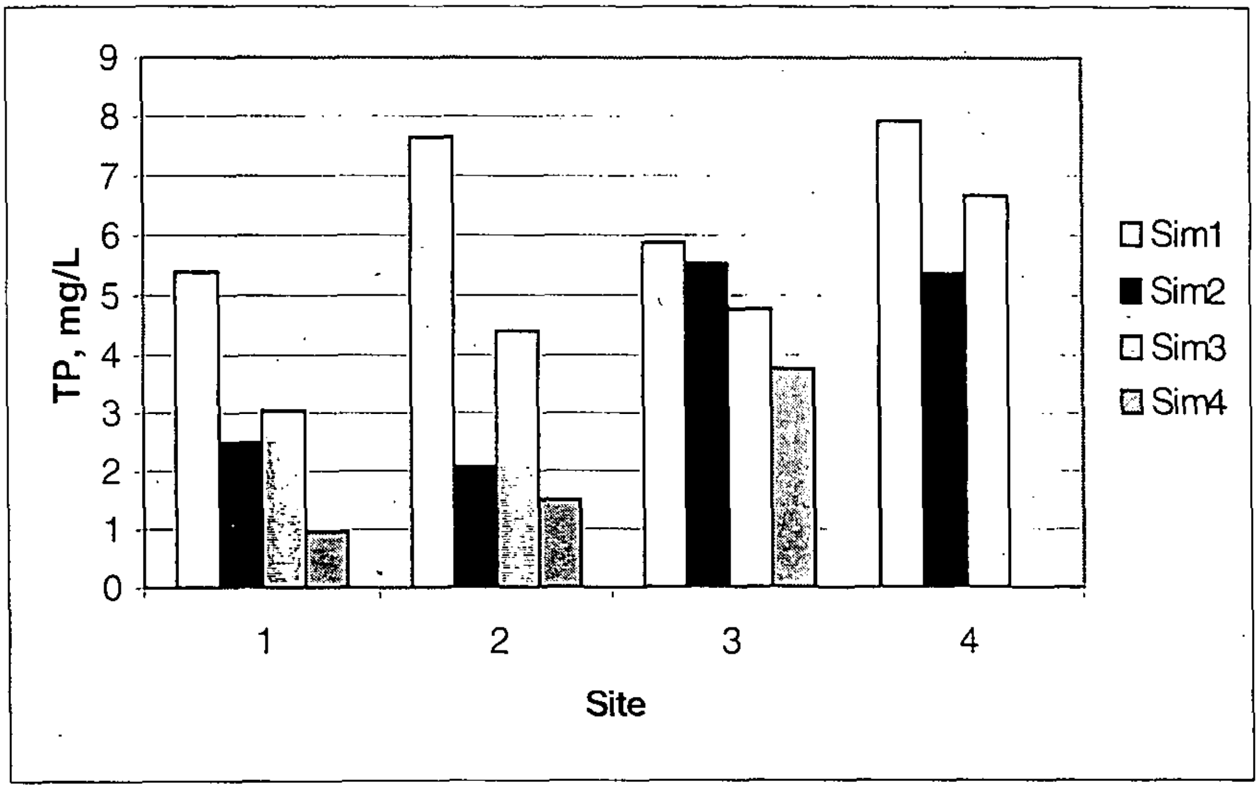


Figure 23: Mean total P concentration in surface runoff for four sites for four rainfall simulations.

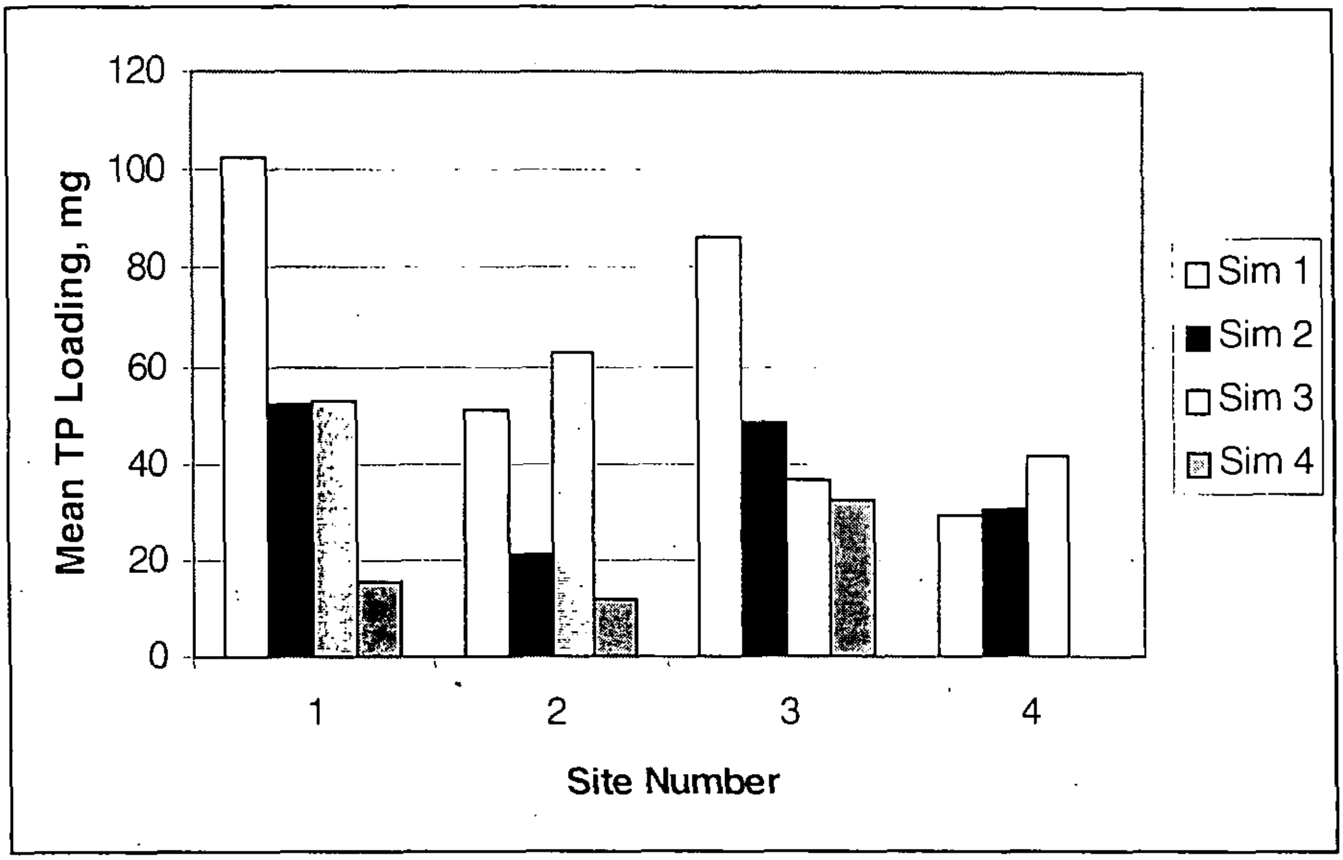


Figure 24: Mean total P loading in surface runoff (P concentration *runoff volume) for four sites for four rainfall simulations.

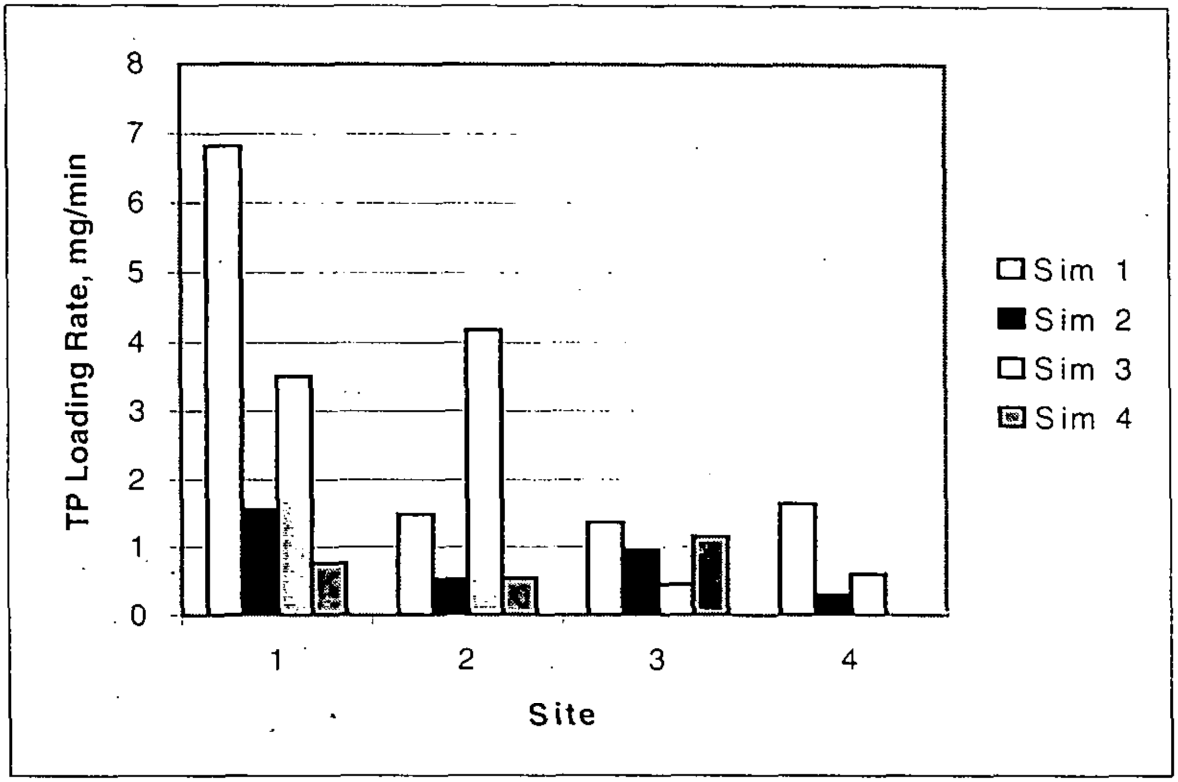


Figure 25: Mean total P loading rate (TP loading in surface runoff/min of rainfall) for four sites for four rainfall simulations.

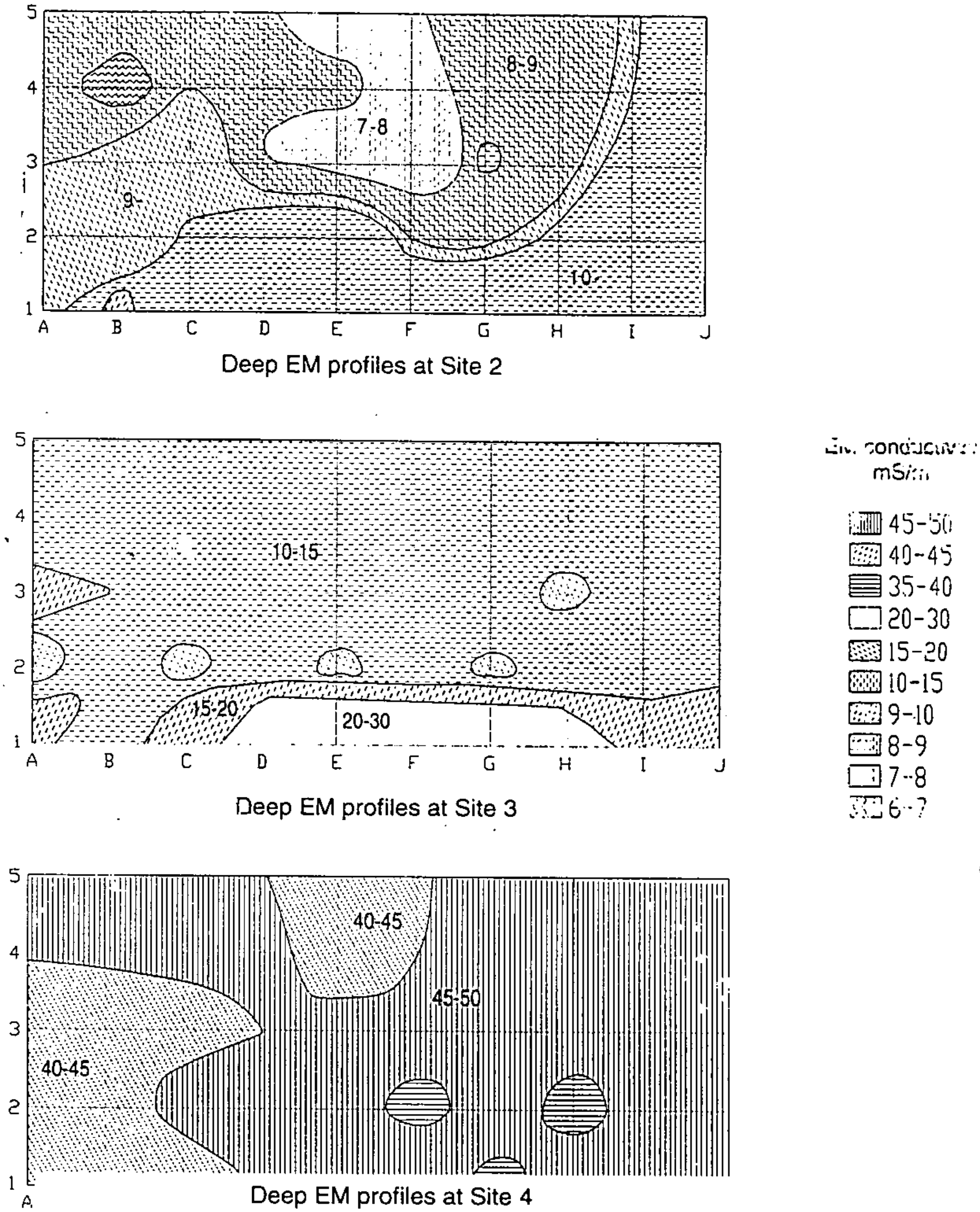


Figure 26: EM34 (deep) profiles at sites 2, 3, and 4.

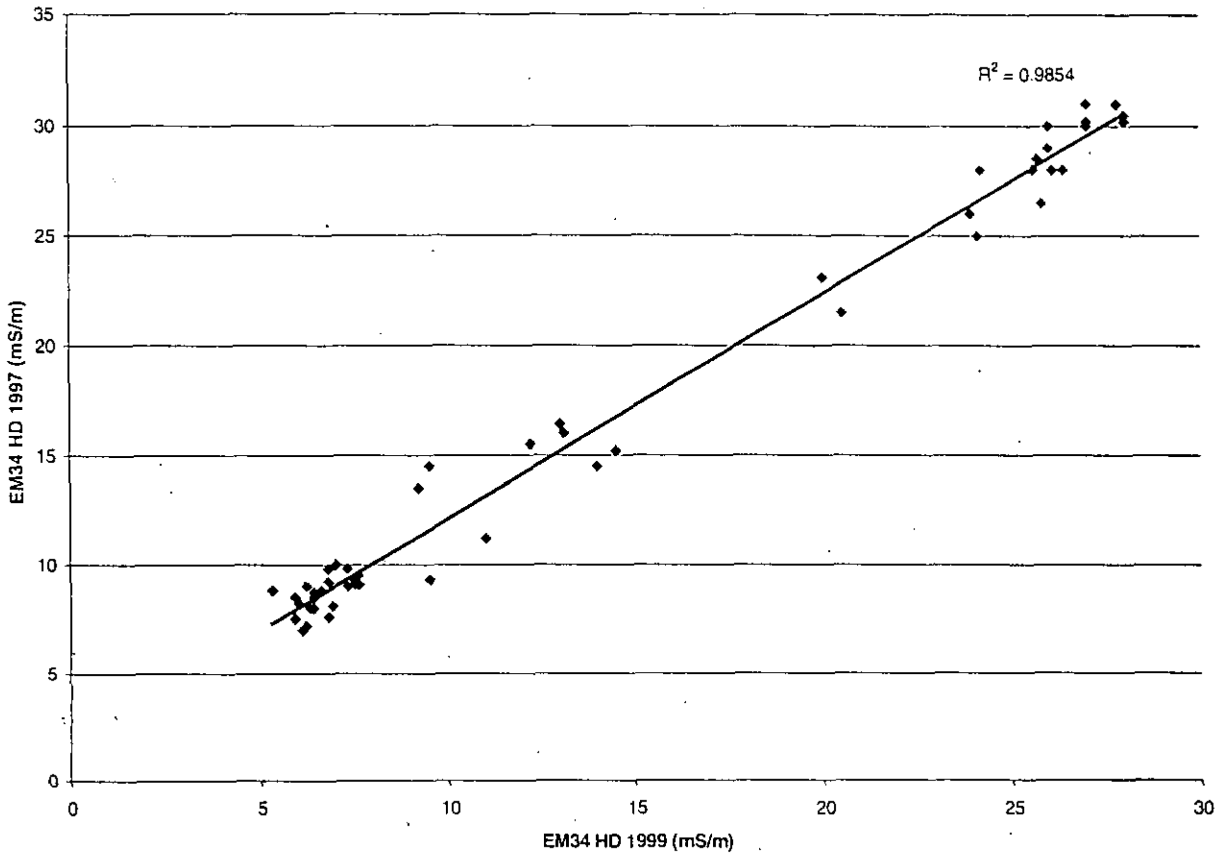


Figure 27. EM34 HD conductivity readings in 1997 and 1999.

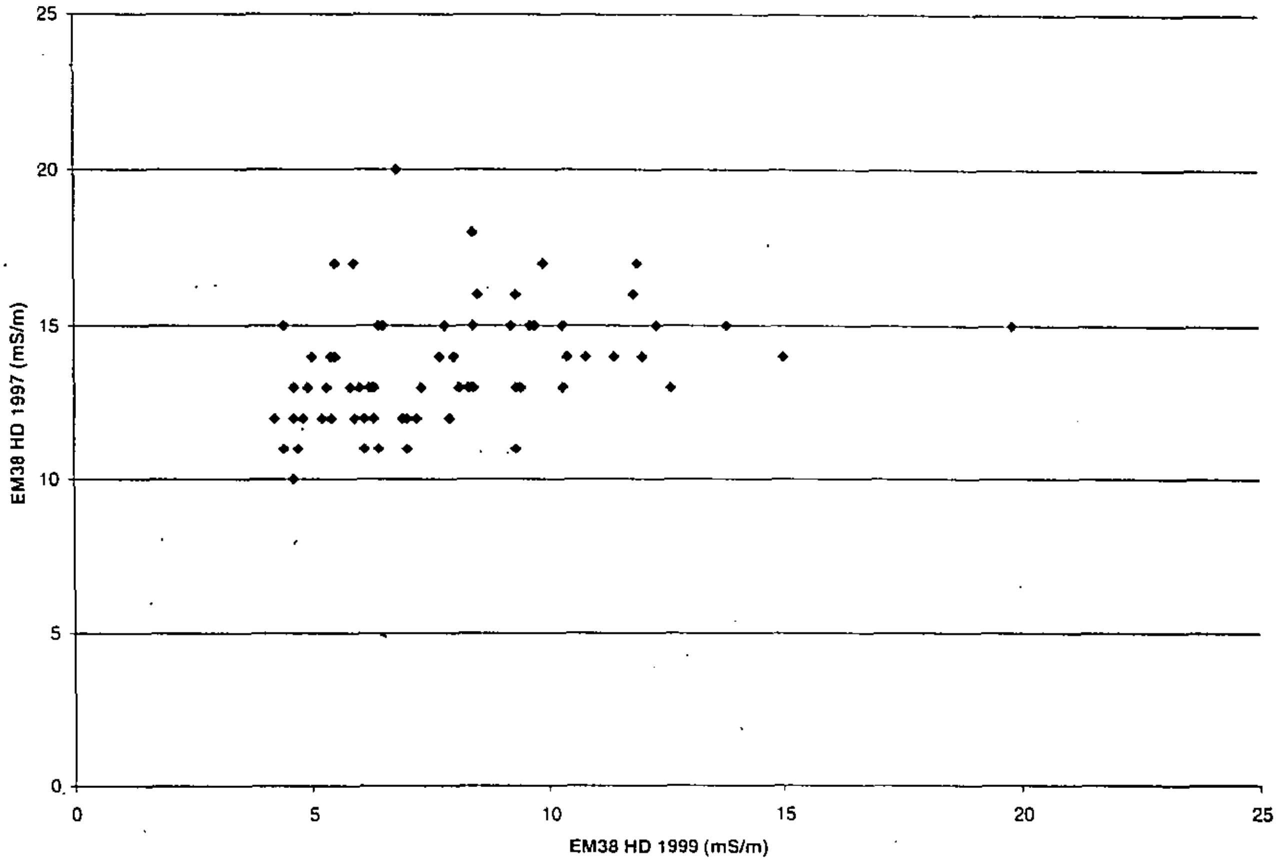


Figure 28. EM38 (shallow) conductivity readings in 1997 and 1999.

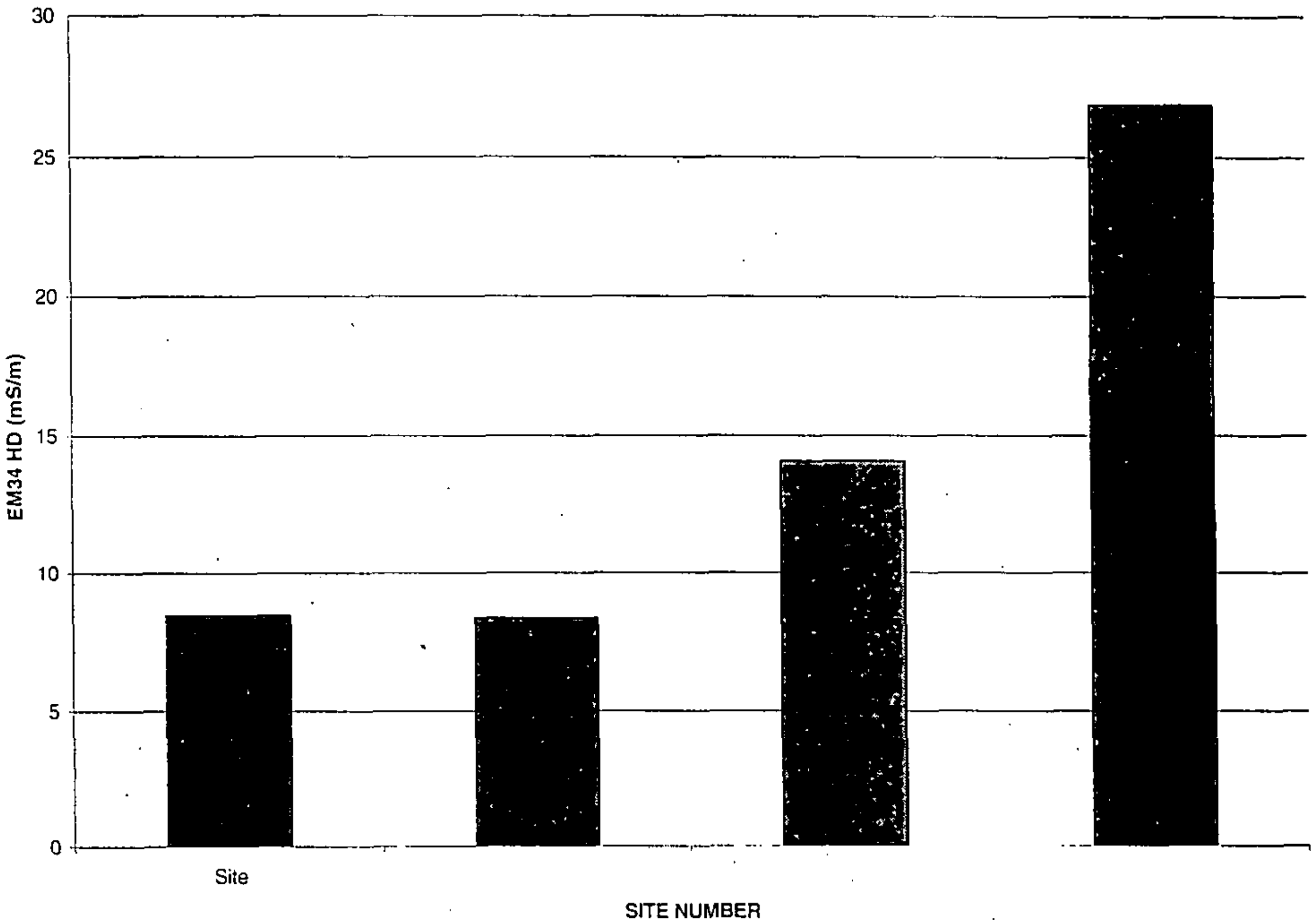


Figure 29. Average EM34 HD response at the four sites.

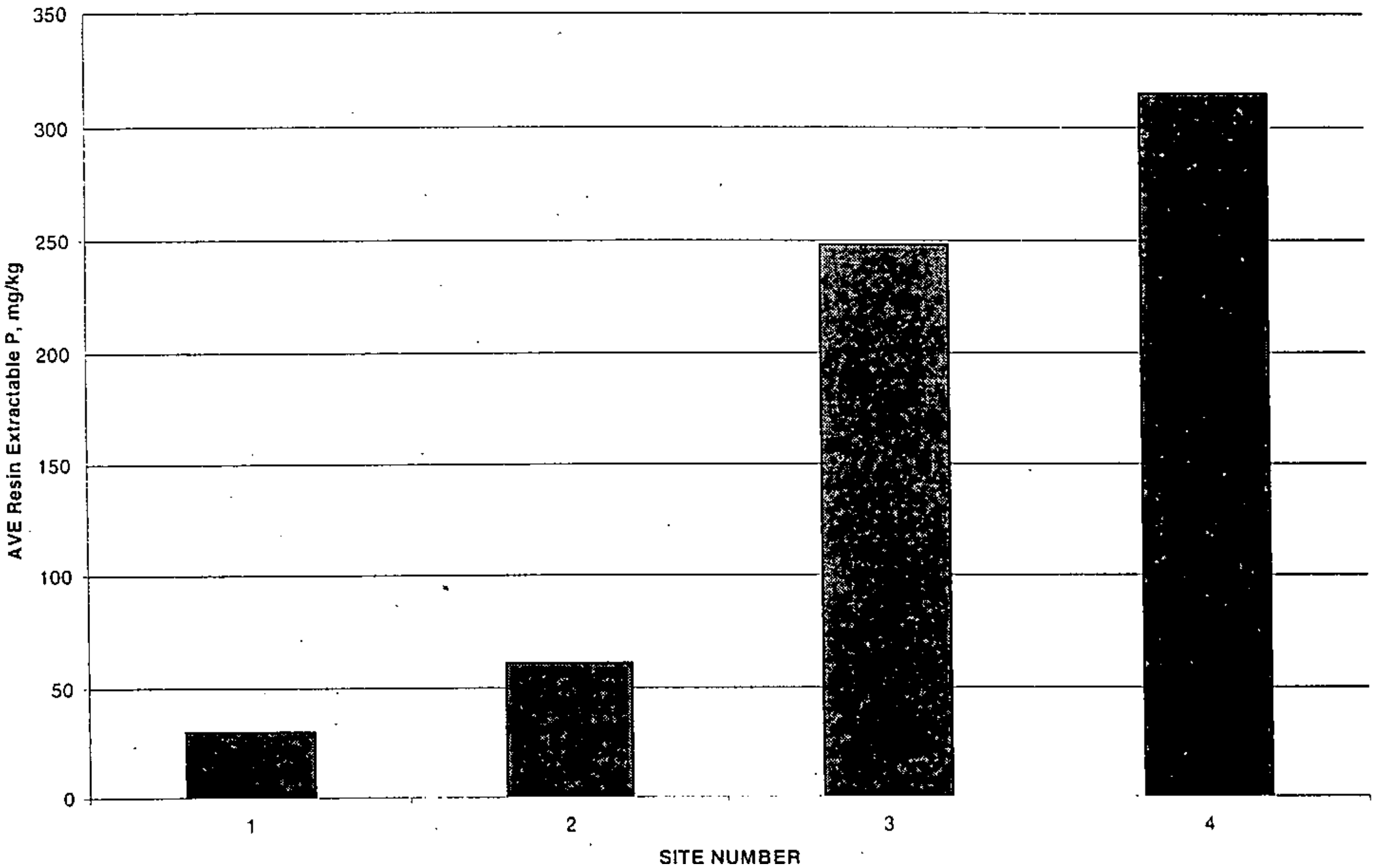


Figure 30. Average resin extractable P content in 0-15 cm soil for four sites.

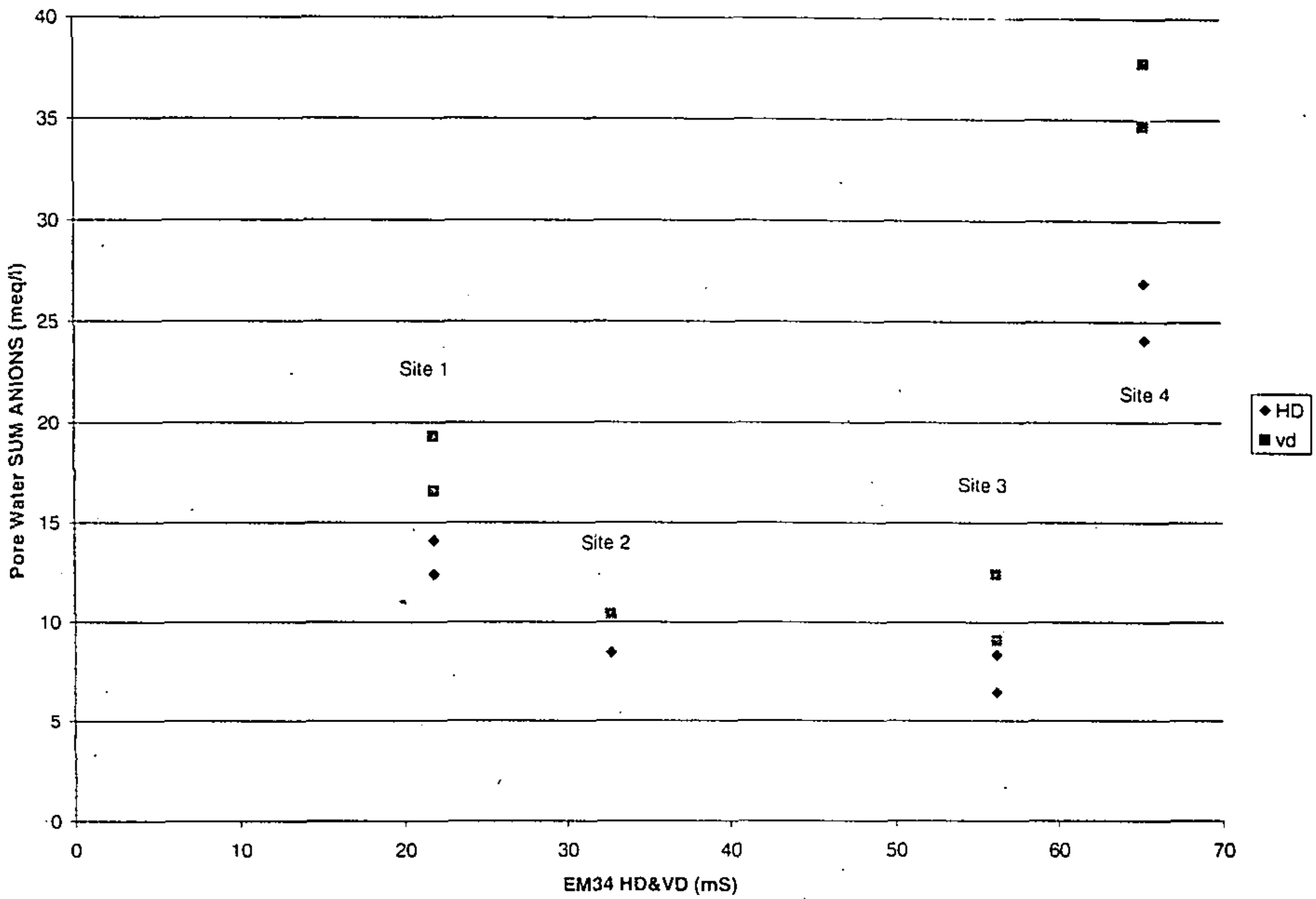


Figure 31: Sum of pore water anion concentration (0-10 ft) vs. EM 34 readings for Sites 1 - 4.

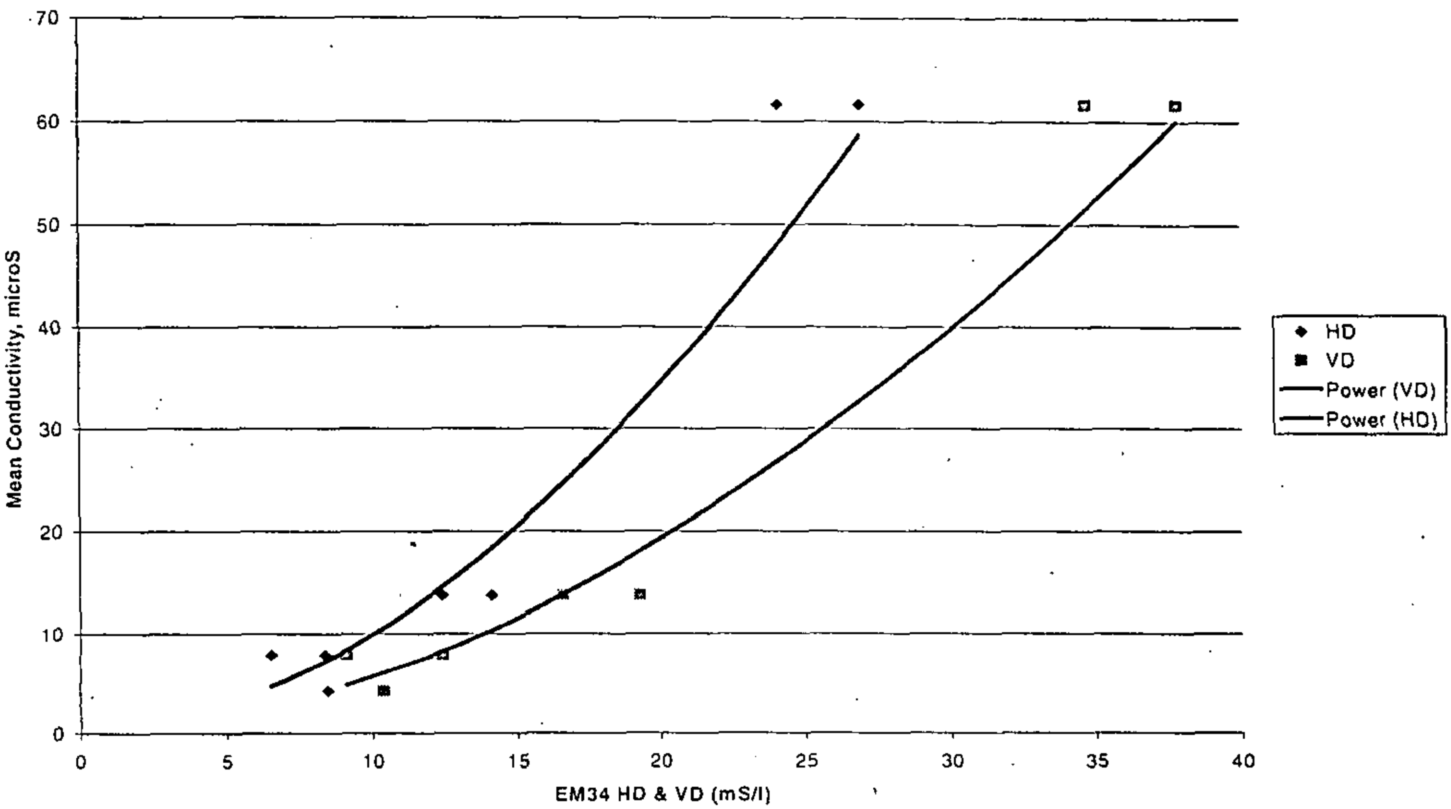


Figure 32. Mean conductivity of surface runoff vs. average EM34 response.

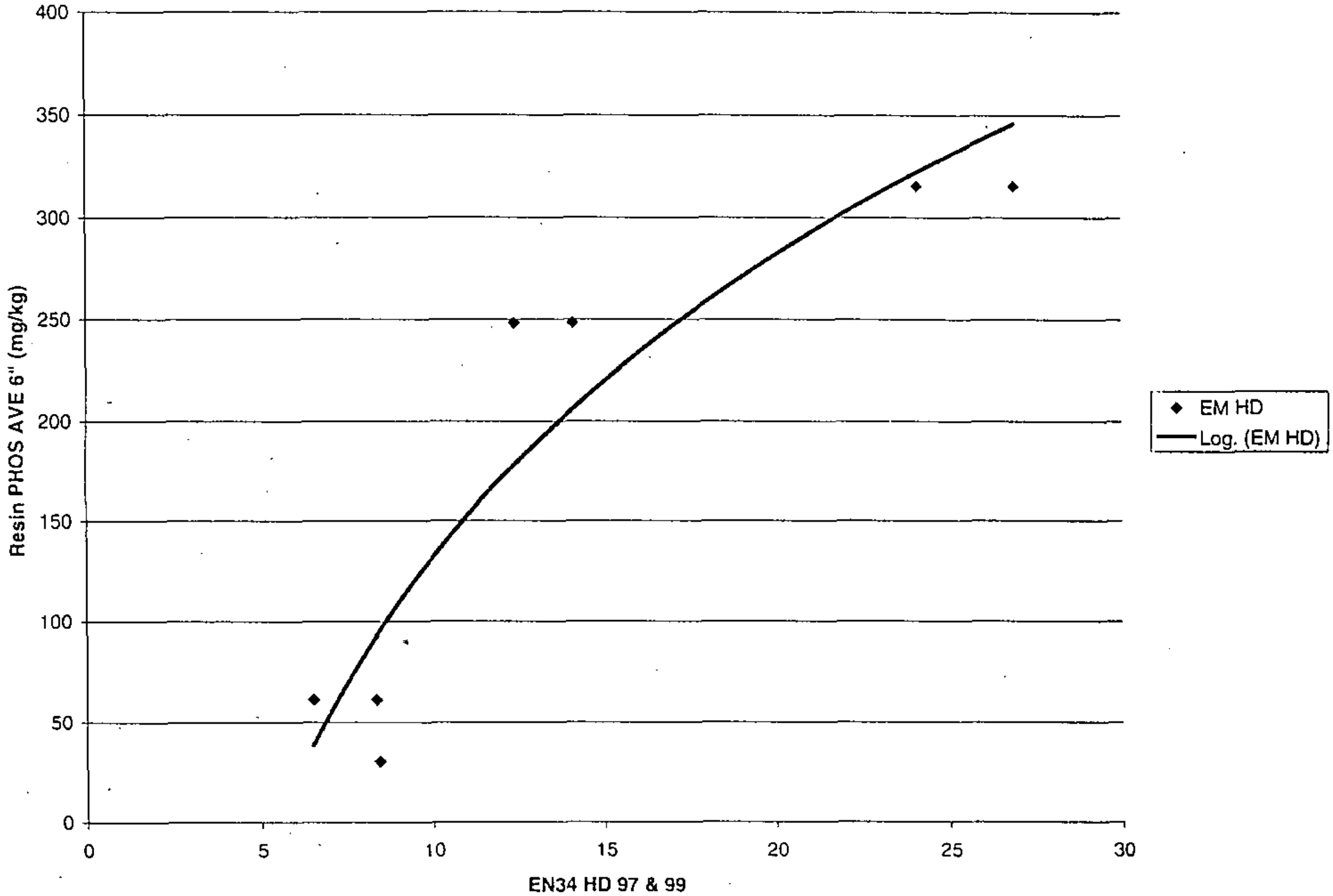


Figure 33. Mean Resin soil P content in 0-15 cm depth vs. mean EM34 response.

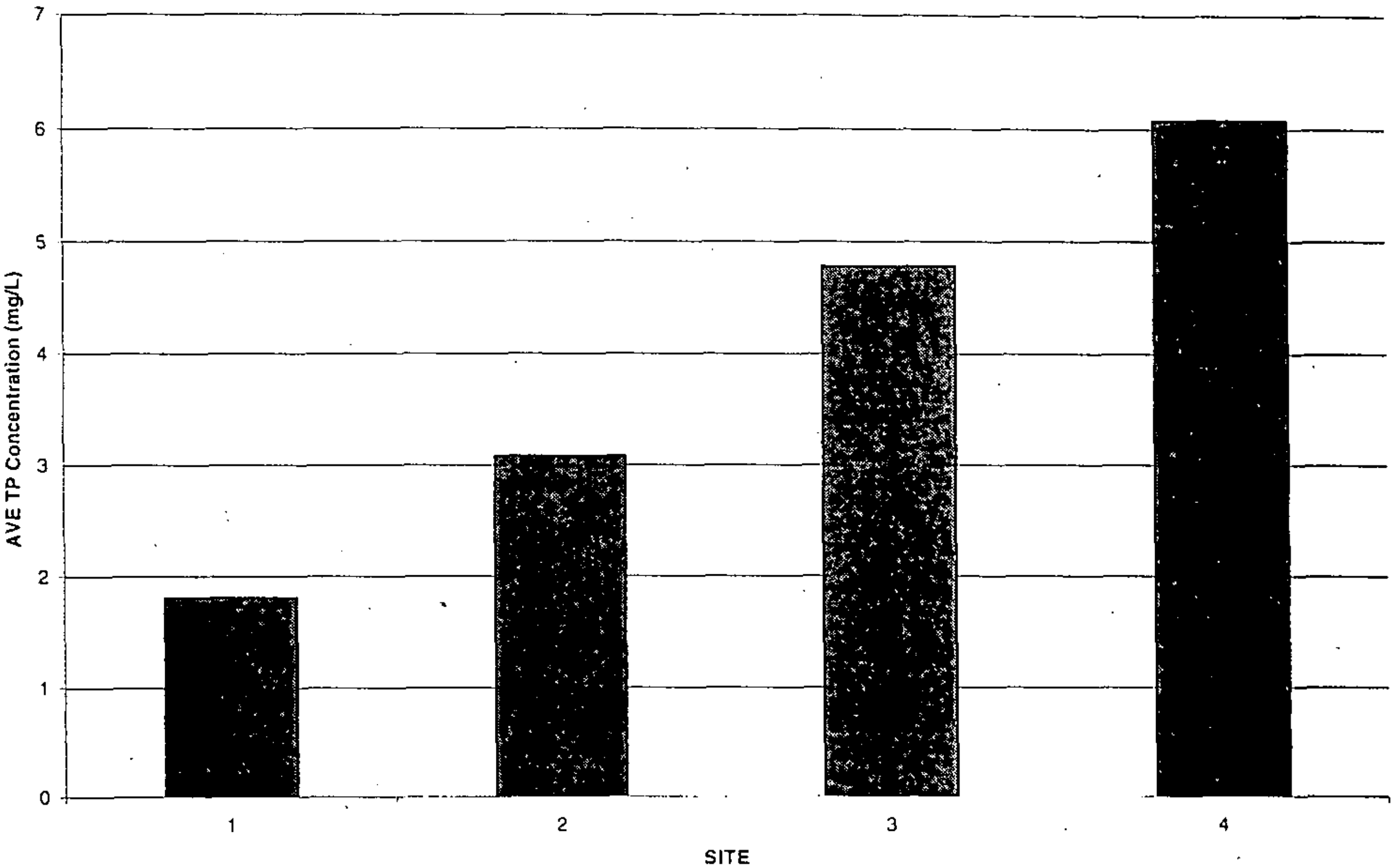


Figure 34. Mean total P concentration in surface runoff for four simulations for the four sites.

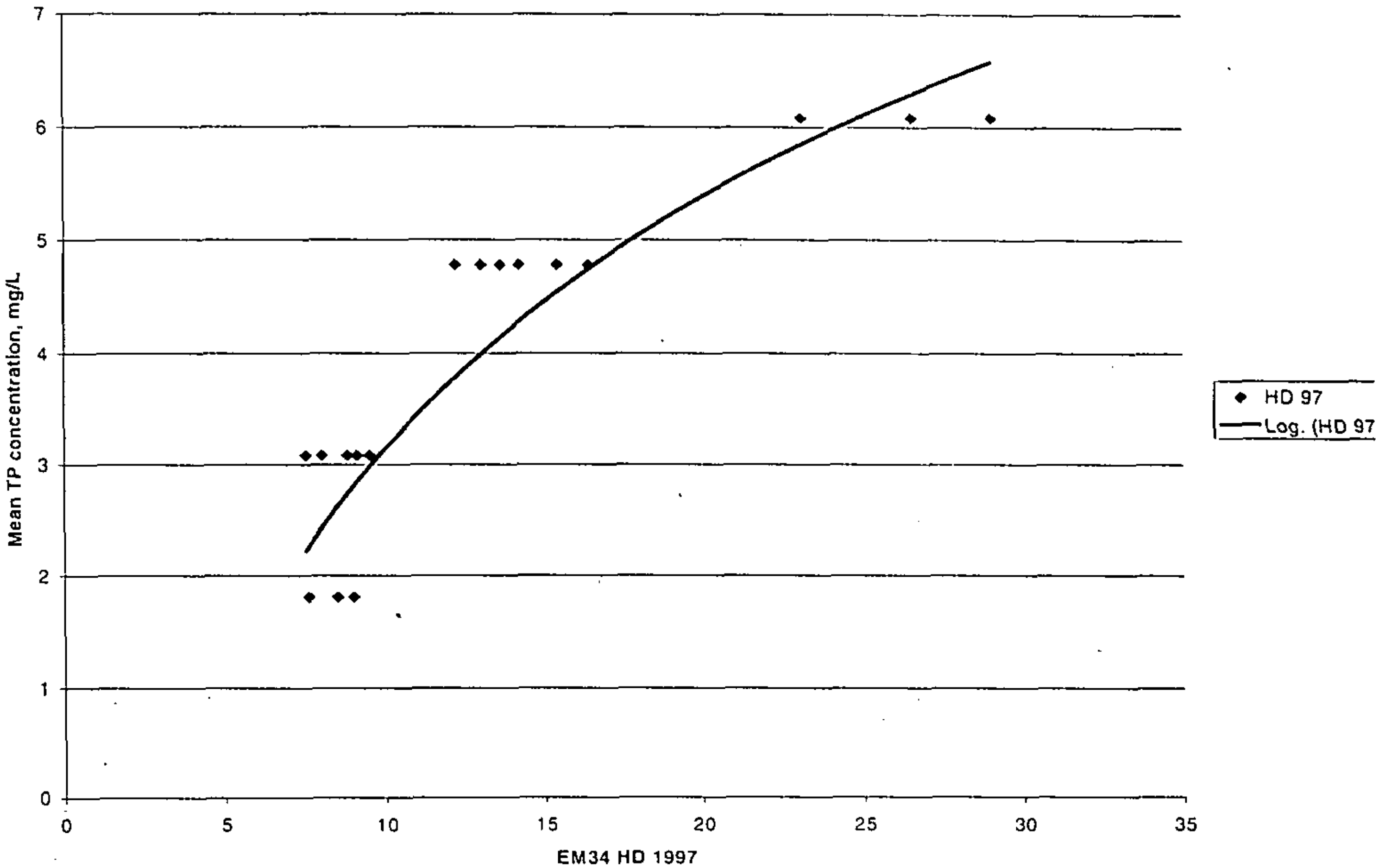


Figure 35. Mean total P concentration in surface runoff for four simulations vs EM34 response.

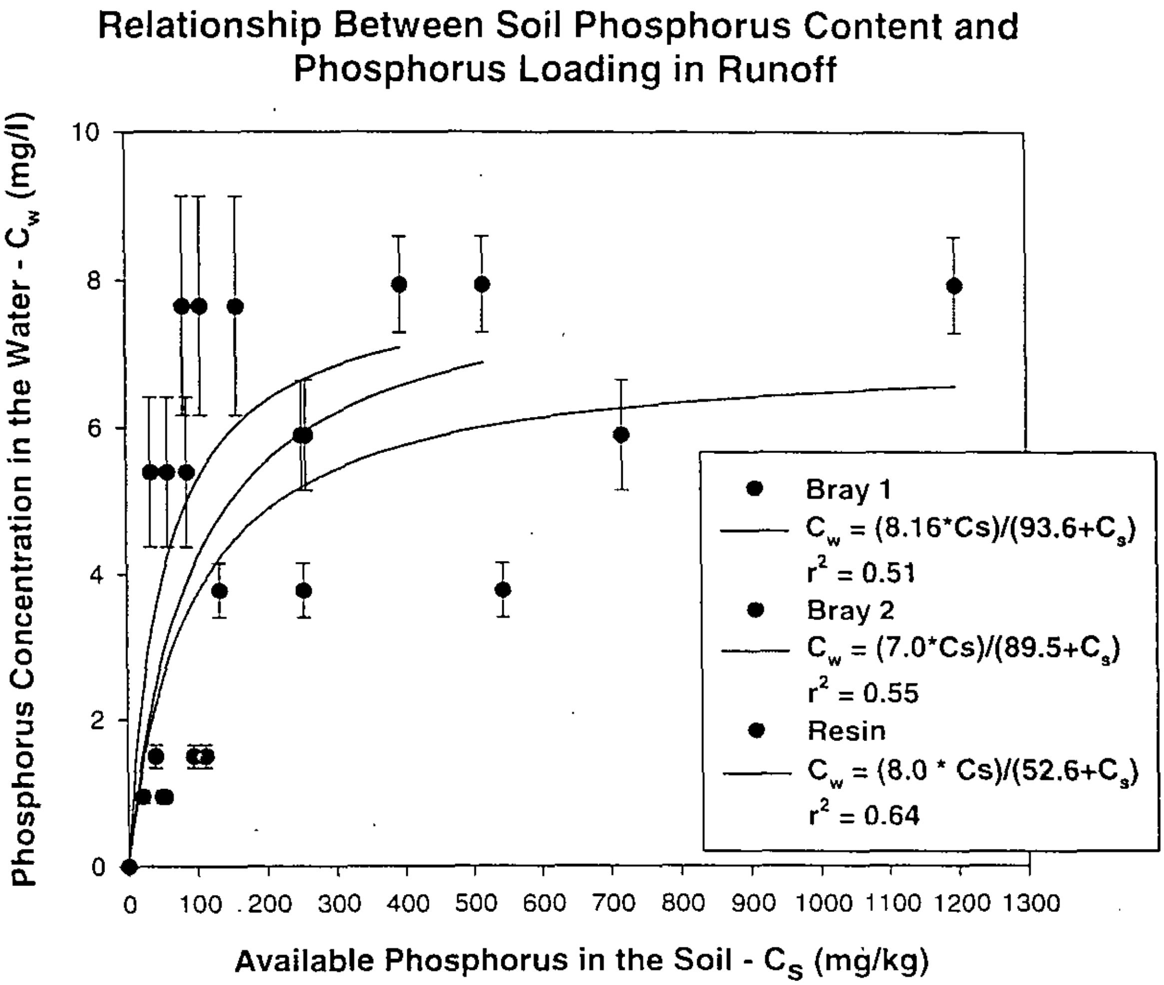


Figure 36 :Relationship between Cs and Cw for Bray 1, Bray 2, and Bray 3 soil analytical methods.

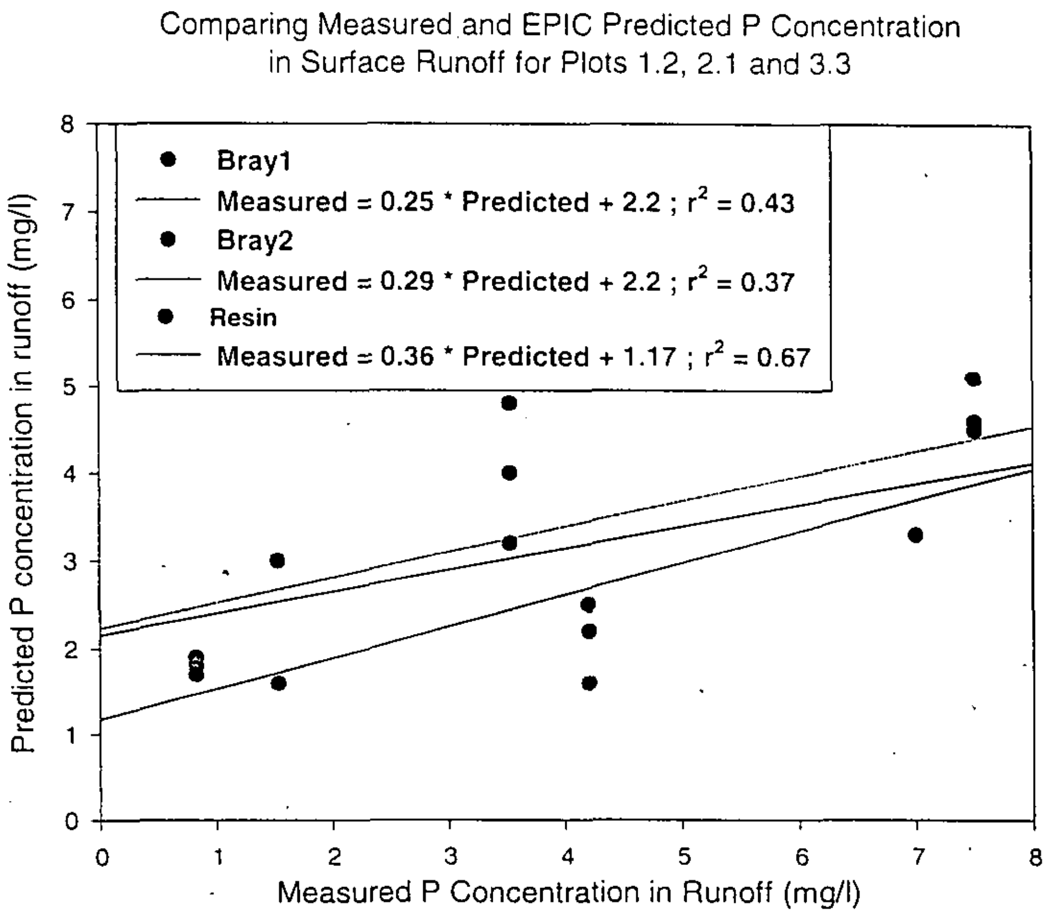
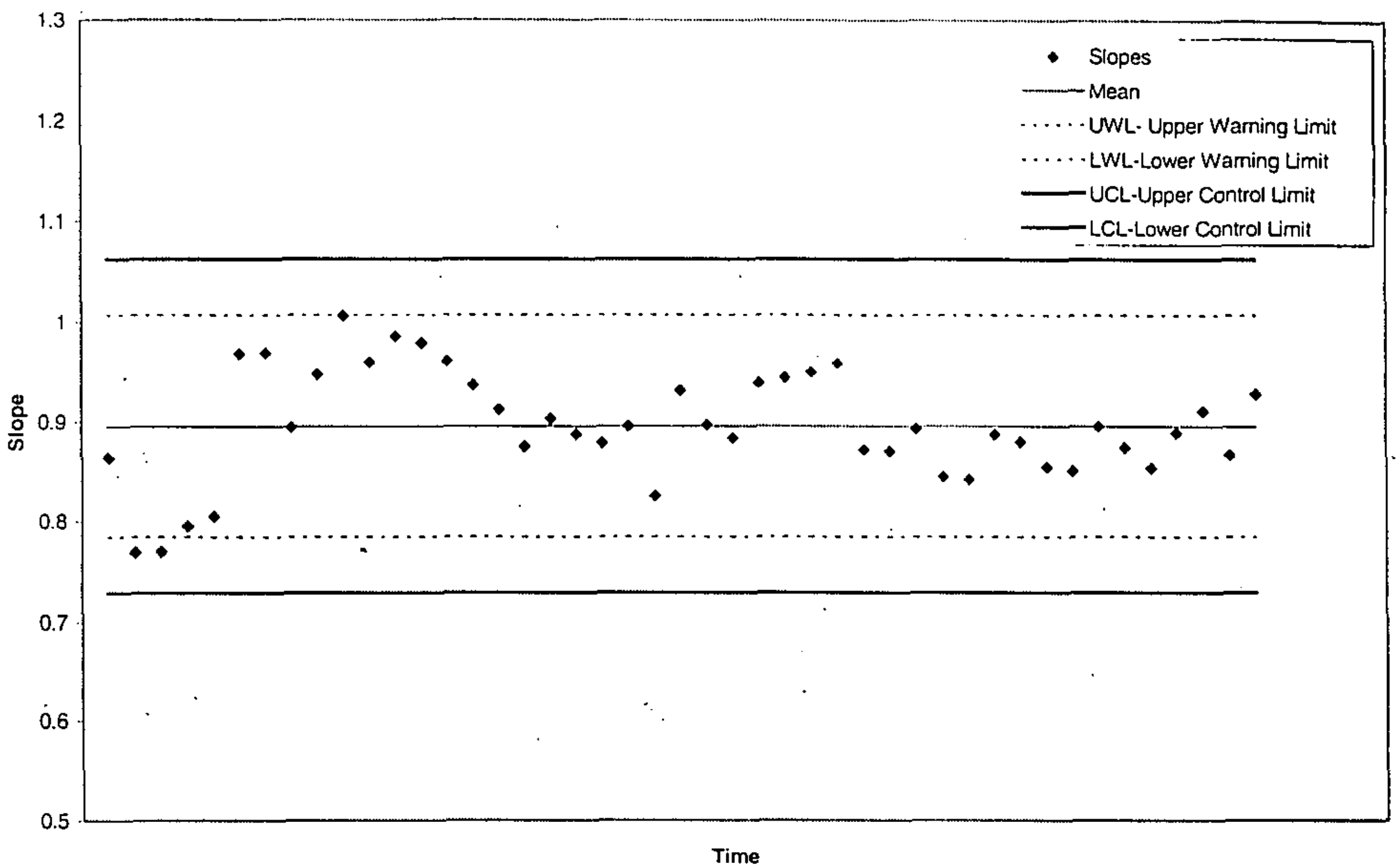


Figure 37 : Measured vs predicted TP concentrations in surface runoff for plots 1.2, 2.1, and 3.3.

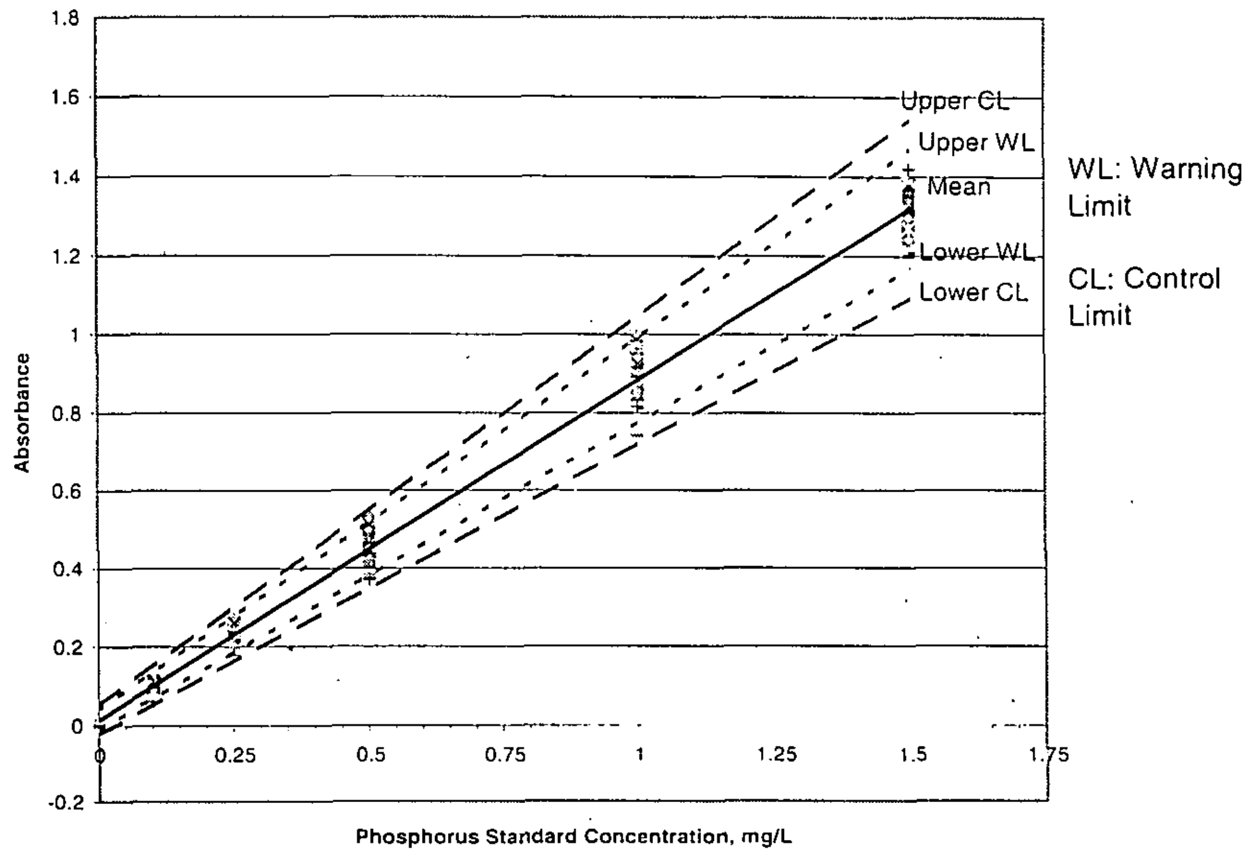
Appendix A: Quality Assurance

1. Phosphorus standards:
The means chart for the standard curves is constructed from the mean and standard deviation, s, of the standard slopes. The means chart includes upper and lower warning levels (WL) which encompass ± 2 standard deviations from the mean, and upper and lower control levels (CL) which encompass ± 3 standard deviations. Approximately 95% of the individual standard values should fall inside the WL area, and 99% of the values should fall within the CL area (APHA, 1995). As seen in Figure A-1, 6.8% of the standard values lie outside of the WL area, while none of the values lie outside the CL area. The three slopes lying outside of the WL occurred during the initial training of the laboratory personnel; over the course of time, the variation in the standard curve slope decreased as the lab analyst gained experience and as one analyst was primarily responsible for preparing and analyzing all standard curves. The range chart for the phosphorus standard curves indicate that all standards were within the WL area (Figure A-2).

2. Rainwater quality:
The phosphorus values for the rainwater collected during each rainfall simulation were low, with mean values of 0.04, 0.03, 0.15, and 0.14 mg/L of total phosphorus (TP) for Simulations 1, 2, 3 and 4, respectively (Table A.1.1). The mean dissolved P (DP) value for the rainwater samples for the four simulations were 0.03, 0.00, 0.07, and 0.06 mg/L, respectively, indicating that the filtering technique used to remove particulate compounds did not contaminate water samples (Table A.1.2)



FigureA.1 : Control chart for mean slope of phosphorus standard curve.



FigureA.2. Range chart for phosphorus standard curves.